Establishing the Norms of Scientific Argumentation in Classrooms

ROSALIND DRIVER*
King's College London, London, UK

PAUL NEWTON
Pre-School Learning Alliance, London, UK

JONATHAN OSBORNE
King's College London, Franklin Wilkins Building, Waterloo Road, London SE1 8WA, UK

Received 21 November 1997; revised 8 October 1998; accepted 1 December 1998

ABSTRACT: Basing its arguments in current perspectives on the nature of the scientific enterprise, which see argument and argumentative practice as a core activity of scientists, this article develops the case for the inclusion and central role of argument in science education. Beginning with a review of the nature of argument, it discusses the function and purpose of dialogic argument in the social construction of scientific knowledge and the interpretation of empirical data. The case is then advanced that any education *about* science, rather than education *in* science, must give the role of argument a high priority if it is to give a fair account of the social practice of science, and develop a knowledge and understanding of the evaluative criteria used to establish scientific theories. Such knowledge is essential to enhance the public understanding of science and improve scientific literacy. The existing literature, and work that has attempted to use argument within science education, is reviewed to show that classroom practice does provide the opportunity to develop young people's ability to construct argument. Furthermore, the case is advanced that the lack of opportunities for the practice of argument within science classrooms, and lack of teacher's pedagogical skills in organizing argumentative discourse within the classroom are significant impediments to progress in the field. © 2000 John Wiley & Sons, Inc. *Sci Ed* **84**:287–312, 2000.

We should not assume that mere contact with science, which is so critical, will make the students think critically. (Rogers, 1948, p. 7)

Correspondence to: J. Osborne; e-mail: jonathan.osborne@kcl.ac.uk
*Deceased

OVERVIEW

This study presents the rationale for a research program in the area of argument in science — an area to which science education has only given scant attention. As argument is a central feature of the resolution of scientific controversies (Fuller, 1997; Taylor, 1996), it is somewhat surprising that science teaching has paid so little attention to a practice that lies at the heart of science. It is our contention that this significant omission has led to important shortcomings in the education that is provided *about* science. It has given a false impression of science as the unproblematic collation of facts about the world, hence making controversies between scientists, whether historical or contemporary, puzzling events (Driver, Leach, Millar, & Scott, 1996; Geddis, 1991). Such a disregard for the practice of argument has also failed to empower students with the ability to critically examine the scientific claims generated by the plethora of socioscientific issues that confront them in their everyday lives (Norris & Phillips, 1994; Solomon, 1991).

Science in schools is commonly portrayed from a "positivist perspective" as a subject in which there are clear "right answers" and where data lead uncontroversially to agreed conclusions. This is a view perhaps most aptly expressed by Schwab who argued that science is "taught as a nearly unmitigated *rhetoric of conclusions* in which the current and temporary constructions of scientific knowledge are conveyed as empirical, literal and irrevocable truths" (Schwab, 1962, p. 24). Consequently, the stock-in-trade of the science teacher is knowledge that is "unequivocal, unquestioned and uncontested" (Claxton, 1991).

Current research into the activities of scientists, however, points to a different picture of science: here, in contrast, the contribution of discursive practices to the construction of scientific knowledge is portrayed as important. Practices, such as assessing alternatives, weighing evidence, interpreting texts, and evaluating the potential viability of scientific claims are all seen as essential components in constructing scientific arguments (Latour & Woolgar, 1986). In making scientific claims, theories are open to challenge and progress is made through dispute, conflict, and paradigm change. Thus, arguments concerning, for example, the appropriateness of an experimental design, or the interpretation of evidence in the light of alternative theories, are seen to be at the heart of science and central to the discourse of scientists (Druker, Chen, & Kelly, 1996). Furthermore, the work of scientists also includes argument in the public domain through journals, conferences, and the wider media. It is through such processes of having claims checked and criticized that "quality control" in science is maintained.

Hence, we would contend that, if science education is to help young people engage with the claims produced by science-in-the-making, science education must give access to these forms of argument through promoting appropriate classroom activities and their associated discursive practices. Such practices, and only such practices, are the means of socializing young people into the norms of scientific argument from which they may gain confidence in their use, and a deeper understanding of their function and value.

In addressing such concerns, our argument is presented in two parts. First, we consider what is meant by argument and its function within science. Second, we examine the place of argument in science education and what is known about its function and use from the extant body of literature.

INTRODUCTION

The central premise of this study is that science education, as currently practiced, still reflects a basically "positivist view" of science in which the book of nature is read by observation and experiment. Our contention is that, to provide adequate science education for young people, it is necessary to reconceptualize the practices of science teaching so as to portray scientific knowledge as *socially constructed.* This change in perspective has major implications for pedagogy, requiring discursive activities, especially argument, to be given a greater prominence. Traditionally, in the UK (and other Anglo-Saxon countries), there has been considerable emphasis on practical, empirical work in science classes. Reconceptualizing the teaching of science in the light of a social contructivist perspective requires, among other matters, the reconsideration of the place of students' experiments and investigations. Rather than portraying empirical work as constituting the basic procedural steps of scientific practice (the "scientific method"), it should be valued for the role it plays in providing evidence for knowledge claims. More fundamentally, what is required is a reconsideration of the role of science education, commonly seen as an introductory *training* in science, emphasizing basic methodological skills and practices, to one that sees its function as an education *about* science, which seeks to empower young people and develop their scientific literacy (Millar & Osborne, 1998).

Arguments for change are not new. Cohen (1952) made an elegant case that science education is based on a number of substantive fallacies, not least of which is the fallacy of miscellaneous information—the belief that a survey course covering a body of unrelated information will be both valuable and valued, when in reality, for most students, it is nothing more than of ephemeral value as a means of passing an examination. The last few decades, however, have seen various practical initiatives to promote changes in teaching that might broaden the perspective and function of science education (see Cross and Price, 1992; Hunt, 1994; Solomon & Aikenhead, 1994; Solomon, Duveen, & Scott, 1992) with the production of sets of good, relevant curriculum materials. However, despite such imaginative initiatives, the dominant view of science, currently portrayed in schools in the UK, is one which has become trapped in a time warp, reinforced by a prescriptive National Curriculum that embodies most, if not all, of Cohen's fallacies.

The "positivist" view of science, placing as it does emphasis on factual recall with confirmatory experiments, denies the role of the historical and social accounts of science, presenting science as a linear succession of successful discoveries. Applications of science, and their social implications, are simply limited to illustrations of the "use" to which scientific knowledge can be put. The more recent introduction of investigative work, which has much to contribute to students' knowledge construction, is generally still interpreted in formulaic ways (Donnelly, Buchan, Jenkins, Laws, & Welford, 1996), and has still failed to transcend the fallacy that there is *a* singular "scientific method"—the belief that science has been the result of the consistent application (without much imagination, thought, or judgment) of a simple set of rules to every situation as it arose. Such a limited perspective inhibits opportunities for students to gain insight into the processes of knowledge construction in science. The closed manner in which practical activities are often framed underplays, or even ignores, the importance of the thinking that needs to go into the planning of those activities; for instance—what is the question that is being addressed in the experiment? How might that question be answered empirically? What alternative methods could be used and how might one select between them? Similarly, the thought that is necessary in the interpretation of results, once these have been obtained, is also frequently underrepresented in the classroom—for instance, what trust can we place in these data? How might these data be interpreted? Are there different possible interpretations (Atkinson & Delamont, 1977)? But, because time and emphasis are not given to such evaluative tasks, the main message from much practical work is that "nature speaks" directly to us from our data and the process of "making sense," the act of interpretation and the human construction of knowledge are completely overlooked in the priorities given in teaching.[1] As Thomas Kuhn so charmingly put it, there is no such thing as "an immaculate perception." Yet this archaic view of science, as solely a process of empirical inquiry dependent on "reading the book of nature," is the image that is predominantly promoted through current science education. It is perhaps of no surprise, therefore, to note that research indicates that this "positivist" perspective is reflected in the views of the nature of science held by most science teachers themselves (Lakin & Wellington, 1994)—a finding which suggests that the remediation of this problem lies, at least in part, with the teachers and their beliefs and values.

In contrast to the image of science presented in science classrooms, Fuller (1997), for instance, has argued that "most of what non-scientists need to know in order to make informed public judgements about science fall under the rubric of history, philosophy, and sociology of science, rather than the technical content of scientific subjects." In a study written by one of the authors, over 10 years ago (Millar & Driver, 1987), the then contemporary rhetoric within science education courses that sought to emphasize "the processes of science" was critiqued. The final section offered, without elaboration, tentative indications of what an alternative perspective on science education might involve without elaboration. This study attempts to advance those implications by presenting a rationale for science pedagogy that is coherent and based on current scholarship and research in the field of science studies and the philosophy of science. It develops the ideas of science educators (Duschl, 1990), social epistemologists (Fuller, 1997), rhetoricians (Taylor, 1996), and science communicators (Gregory & Miller, 1998) who all argue for presenting science as a process in which scientific knowledge is socially constructed, and in which discursive activity is central to the process of science. Therefore, it is our contention that such a pedagogy would give a central place and role to argumentation.

In this study, therefore, we develop our case for the centrality of argument in science on three strands of literature: (1) current perspectives on the nature of the scientific enterprise itself; (2) an analysis of the role and function of argument within science; and (3) emerging priorities that require science education to promote a better understanding of science and its nature and enhance the public understanding of science. First, we consider it essential to examine what is meant by "argument" as our use of the term, and others, needs to be clearly distinguished from the negative connotations associated with the lay use of the word.

WHAT IS MEANT BY "ARGUMENT"?

Logic and Argument

The field of argument studies came to be established when a distinction was made between, on the one hand, the study of logic, which was taken to be the disembedded rules for producing correct inferences from given premises and, on the other hand, the study of how people in specific situations actually reason from premises to conclusions. Whereas logic is seen as an academic discipline that presents decontextualized rules for relating premises to conclusions, arguing is a *human practice* that is situated in specific social settings. From this situated perspective, argument can be seen to take place as an *individual*

[1] The process by which learners make sense of natural phenomena is also further complicated by the fact that the regularities in nature are often only displayed with care, and teachers frequently need to "manage" a demonstration to make a clear case (Nott & Smith, 1995).

activity, through thinking and writing, or as a *social* activity taking place within a group—a negotiated social act within a specific community.

There are two emphases on the meaning of argument in the educational literature. The first is described in the *Oxford English Dictionary* as "advancing a reason for or against a proposition or course of action." This interpretation of argument is described as *"rhetorical"* by Kuhn (1992) or *"didactic"* by Boulter and Gilbert (1995). In this mode, argument is being used to tell others and to persuade them of the strength of the case being put. Examples of such arguments are common in science lessons in which a teacher provides a scientific explanation to a class or to a group of students with the intent of helping them to see it as reasonable. As Kress, Ogborn, Jewitt, and Tsatsarleis (1998) pointed out, nature does not "speak for itself," particularly when the teacher is trying to convince pupils that we live at the bottom of a sea of air; that objects continue in motion forever; or that inherited characteristics are transmitted via a chemical messenger. Russell (1983) provided an insightful analysis of such teacher-led classroom discourse determining the kind of authority used by teachers to substantiate knowledge claims when arguing in this way. Drawing on the distinction made by Peters (1966) between *rational authority* (where teachers supply reasons and evidence for knowledge claims), and *traditional authority* (where teachers draw on their institutional positions for support), Russell showed how teachers' discourse frequently relied on traditional authority and, consequently, overlooked reasons and evidence. Yet, if a central goal of science education is to persuade students to seek evidence and reasons for the ideas we hold, and to take them seriously as a guide for belief and action, then the reliance on traditional authority is not only a misrepresentation of the norms of scientific argument but also distorts student understanding of the nature of scientific authority. Norris (1997), with whom we would concur, goes further, arguing that:

> To ask of other human beings that they accept and memorize what the science teacher says, without any concern for the meaning and justification of what is said, is to treat those human beings with disrespect and is to show insufficient care for their welfare. It treats them with a disrespect, because students exist on a moral par with their teachers, and therefore have a right to expect from their teachers reasons for what the teachers wish them to believe. It shows insufficient care for the welfare of students, because possessing beliefs that one is unable to justify is poor currency when one needs beliefs that can reliably guide action. (p. 252)

Moreover, the rhetorical form of argument is one-sided and has limitations in educational settings. It occurs when teachers marshal evidence and construct arguments for their pupils. If young people are to develop the skills of scientific argument for themselves, and not just provide an audience for the teachers' reasoning, then science classrooms will need to offer opportunities to practice such reasoning for themselves—that is, to articulate reasons for supporting a particular claim; to attempt to persuade or convince their peers; to express doubts; to ask questions; to relate alternate views; and to point out what is not known. This is where the next form of argument has value.

The second *"dialogical"* or *"multivoiced"* interpretation of argument is involved when different perspectives are being examined and the purpose is to reach agreement on acceptable claims or courses of action. Such *dialogical* arguments can take place within an individual or within a social group. Constructing an argument involves considering alternative positions. Even arguments constructed by an individual are put together by thinking of cases that the arguments have to contest. Clearly, within a group, the *multivoiced* nature of argument construction is much more obvious as individuals take differing positions over the claims advanced, and hence, the nature of the argument that can be put together. Zeidler (1997) comments of such a process that:

> . . . because the idea of dialogic interaction and argumentation involves attempting to find a fit among one's beliefs, other individuals' beliefs, and the problem solving task at hand, Laudan's (1984) reticulated view of theory change is helpful in considering the nature of argument. . . . This view holds that change in the way people think does not happen in incremental linear steps: rather mutual factors (other's perspectives) continually restructure, alter, or fine tune a students' goals, procedures and personal knowledge. (p. 485)

Thus, we are persuaded to view the practice of argument by pupils in groups as an important mechanism for scaffolding the construction of argument by pupils individually.

Argument as Rational

One of the main areas of dispute about argumentation is the basis on which persuasion is deemed to take place. As Siegel (1995) states "Argumentation—whatever else it may be—is aimed at the *rational* resolution of questions, issues and disputes." A different position is adopted by those who see argumentation as an activity aimed at using any available mechanism of persuasion (Billig, 1987). This was reflected in the statement by Van Eemeren (1985) that: "Argumentation is a social, intellectual, verbal activity serving to justify or refute an opinion, consisting of statements directed towards obtaining the approbation of an audience." A third view is offered by Binkley (1995) who described the process of arguing as "constructing a reckoning." This he saw as a creative process by which thoughts are built into an abstract structure linking premises with conclusions whose consequence is that "when you have finished building your structure your thoughts will be organized in a certain way." He described, in a helpful manner, the interplay of the rational presentation of an argument and the issue of persuasion of an audience in the construction of a reckoning as one in which:

> The arguer . . . seeks to influence judgement by getting the audience to construct a reckoning supporting the desired judgement, and the arguer does this by supplying the audience with ingredients for such a reckoning. When I argue with you it is as if I should try to get you to make a cake by plying you with eggs, flour, sugar and baking powder: in the end, I hope, *you* will do the mixing and baking. This is why it is that, when your judgement has been influenced by someone's successful arguing, you have the feeling that not only that person, but reason itself has persuaded you. (p. 138)

There is a clear corollary here with the *rational authority* discussed by Russell (1983), where attention is paid to the need for evidence and rational argument if science teaching is to make provision for the intellectual independence of students (Munby, 1980; Norris, 1997).

The central concern of this study is to search for norms in argumentative discourse. Hence, this project is at odds with the postmodern perspectives which would reject the "enlightenment" philosophy of the value of rationality. We do not intend to go into the arguments about the postmodern position here. Interested readers may find the points made by Siegel (1995) to be pertinent. However, the following quote by the philosopher Hilary Putnam (1982) presents a position which we find convincing:

> If reason is both transcendent and immanent, then philosophy, as culture-bound reflection and argument about eternal questions, is both in time and eternity. We don't have an Archimedian point; we always speak the language of a time and a place; but the rightness and wrongness of what we say is not just for a time and a place. (p. 21)

The position being argued here is that any statement we make, whether of a universal principle or a more local claim, will be situated and located in our culture and in our particular stance and commitments. But this does not necessarily mean that such statements cannot be universal. This is a particularly important point in science. We recognize that claims that scientists make are influenced by the scientific and cultural environment of the time and by the commitments and value positions of the scientists themselves. However, this does not mean that the claims scientists make are completely relative or that scientists can claim what they like or that there is no way to evaluate the "degree of truth" in any claim. For all claims have to be evaluated against the recalcitrance of the material world using a range of criteria that enables the determination of the best choice. It is in this sense that we see argument as a rational process.

Development of Argumentation Theory

Argumentation theory is a field which has been developing over several decades. A seminal contribution was made by Toulmin (1958) in his book, *The Uses of Argument.* Here Toulmin made a break with the traditional field of logic and put forward the case for studying the ways people argue in natural settings. Based on his analysis of arguments in a range of contexts, including legal settings and arguments in science, Toulmin presented a model that describes the constitutive elements of argumentation and represents the functional relationships between them. This account is still influential and, in recent years, it has been drawn on increasingly by science educators (and educators in other subject areas) to provide a template for the description of students' arguments (Druker, Chen, & Kelly, 1996; Jiménez-Aleíxandre, Bugallo-Rodríguez, & Duschl, 1997; Krummheuer, 1995; Russell 1983).

Essentially, Toulmin's model specifies the components in reasoning from data to a conclusion or knowledge claim. The main components identified by Toulmin are:

- *Data:* these are the facts that those involved in the argument appeal to in support of their claim.
- *Claim:* this is the conclusion whose merits are to be established.
- *Warrants:* these are the reasons (rules, principles, etc.) that are proposed to justify the connections between the data and the knowledge claim, or conclusion.
- *Backing:* these are basic assumptions, usually taken to be commonly agreed that provide the justification for particular warrants.

Based on this model, the basic structure of argument as represented in sentences is thus: because (*data*) . . . since (*warrant*) . . . on account of (*backing*) . . . therefore (*conclusion*).

In addition, Toulmin identified two other features in more complex arguments:

- *Qualifiers:* these specify the conditions under which the claim can be taken as true; they represent limitations on the claim.
- *Rebuttals:* these specify the conditions when the claim will not be true.

Toulmin's analysis, however, is limited as, although it can be used to assess the structure of arguments, it does not lead to judgments about their correctness. As he himself pointed out, it is necessary, if judgments of this kind are to be made, that subject knowledge is incorporated for arguments to be evaluated. Furthermore, Toulmin's scheme presents argumentation in a decontextualized way. No recognition is given to the interactional aspects of argument as a speech event, or that it is a discourse phenomenon that is influenced by the linguistic and situational contexts in which the specific argument is embedded. In analyzing actual arguments it is necessary to take these factors into account, and therefore, some interpretation of the text is necessary. For example: (i) the same statement may have a different meaning in a different context, so the context needs to be taken into account in inferring meaning; (ii) parts of arguments such as warrants are often not explicitly stated in speech but are implicit; (iii) in the natural flow of conversation points are not necessarily developed sequentially and reference has to be made across extensive sections of the text to identify features of the argument; and (iv) not all points are made through speech as some are made through semiotic gestures, pointing at objects, nodding, etc., especially in science where manipulable materials are used. Moreover, illustrations and graphics are no longer supplementary but a central communicative feature of texts.

The social relations within the group developing an argument also need to be taken into consideration. For instance, are they contributing to the co-construction of a single argument? Are they developing their separate lines of reasoning? How do the assumed roles of the different members of the group influence the way the argument progresses and the progress made by the group? As a result of many studies of learning in groups it is now recognized that understanding in such situations is a product of both cognitive and social factors (Alexopoulou & Driver, 1997; Richmond & Shriley, 1996) and, in order to interpret the products of group discussion, both these dimensions need to be taken into account in the analysis.

A number of further approaches to argumentation theory have been developed. In some cases the theoretical position is a purely descriptive one—the approach being to provide an analytical account of argument as it is practiced. Other positions attempt to develop norms, criteria and procedures for analysis, and evaluation and construction of arguments. For example, Blair and Johnson (1987) identified three criteria that the premises of an argument must satisfy: "relevance" (is there an adequate relationship between the contents of the premises and the conclusion?); "sufficiency" (does the premise provide enough evidence for the conclusion?); and "acceptability" (are the premises true, probable, or reliable?). Kuhn (1993), in her research into the arguments used by young people and adults about social issues, used a framework for dialogic argument that included: describing and justifying theories; being able to present alternative theories; being able to present counterarguments; and being able to provide rebuttals.

In contrast, Cerbin (referred to in Marttunen, 1994) chose to emphasize the skills of recognizing, composing, and evaluating arguments. His proposals are based on Toulmin's analysis of the components of an argument (a claim, grounds for the claim, warrants, backing, a qualifier and rebuttal) and he argued that a person who is skilled in informal argumentation possesses the ability to identify these components and to evaluate them. Any evaluation of argument must focus on: (a) the clarity of the claim; (b) the relevance and sufficiency of the grounds; (c) the relevance of the warrant; and (d) whether exceptions have been taken into account in drawing conclusions and whether counterarguments have been presented.

All of these more recent developments in argumentation theory indicate that argument is *socially situated.* Hence, any educational program designed to enhance processes of argumentation will require not only cognitive models of argument, but will also need an understanding of the social and cultural settings in which argument is carried out. In education, therefore, it is necessary to pay attention not only to the ways in which students understand the argument process, but also to the social skills necessary for conducting arguments in groups.

In summary, we contend that argumentation theory can provide a theoretical basis for developing tools to analyze and improve argumentative discourse, either in speech or in writing. For, if our educational aim is to be achieved, it is important that there are ways of both analyzing and evaluating written and spoken arguments. Such theoretical tools are necessary: (i) to inform educational interventions designed to improve the quality of argumentation; (ii) to inform teachers about what to look for and how to guide their students' arguments; (iii) to help students to become aware of the nature and structure of arguments; and (iv) to inform the assessment of students' arguments in order to monitor their progress.

SCIENCE AND ARGUMENT

In order to advance our case, we now need to consider the way in which science develops grounds for its knowledge claims; that is, we need to consider the epistemology of science and review the place of argument in science. As a preamble to this section it is important to make a distinction between the *natural world*, on one hand, a world that exists and that impinges on our thoughts and actions, and, on the other hand, our *knowledge of that world*. Whereas we assume that the natural world exists and has consistent properties, we do not have direct access to that world, and hence, our knowledge of it is constructed. Knowledge, therefore, is a human construction. Over the centuries the community of scientists, through its endeavors, has been extending our knowledge and we assume that this process will continue. Scientific knowledge as a social construction is thus provisional. (However, it is important to distinguish between ideas that have stood the test of time and form a central body of secure knowledge, and knowledge that is being produced by developing fields—science-in-the-making—where there is still dispute and controversy). This distinction between the status of the natural world on one hand (as an assumed reality) and our knowledge of it on the other (as a human construction) is important to keep in mind in developing our case.

Unlike the content of science, where we can claim that science over the centuries has provided many robust and enduring explanations for natural phenomena, there is much disagreement concerning the way that science is carried out. (For a review of a number of contemporary positions, see Driver et al. [1996], Chapter 3.) Despite this we argue that there has been a general trend, over the last half century, away from seeing science as an empirical process, where claims to truth are grounded in observation, and where conclusions are seen to be unproblematic deductions from such observations. Instead, the shift in position has been toward a view of science as a social process of knowledge construction that involves conjecture, rhetoric, and argument (Taylor, 1996). This perspective recognizes that observations are theory-laden (Hanson, 1958; Kuhn, 1962) and that, therefore, it is not possible to ground claims for truth in observation alone. Rather, claims are seen to be grounded through the process of argument—relating the imaginative conjectures of scientists to the evidence available (evidence which itself needs to be open to scrutiny in terms of the way it is framed conceptually and the trust that can be placed in it from the point of view of reliability and validity).

Giere (1991) presented a useful, although simplified, model to represent the ways in which reasoning and argument come into the processes of establishing scientific knowledge claims. This model is shown diagrammatically in Figure 1. As the arrows on the diagram show, establishing a knowledge claim in science involves more complex processes than

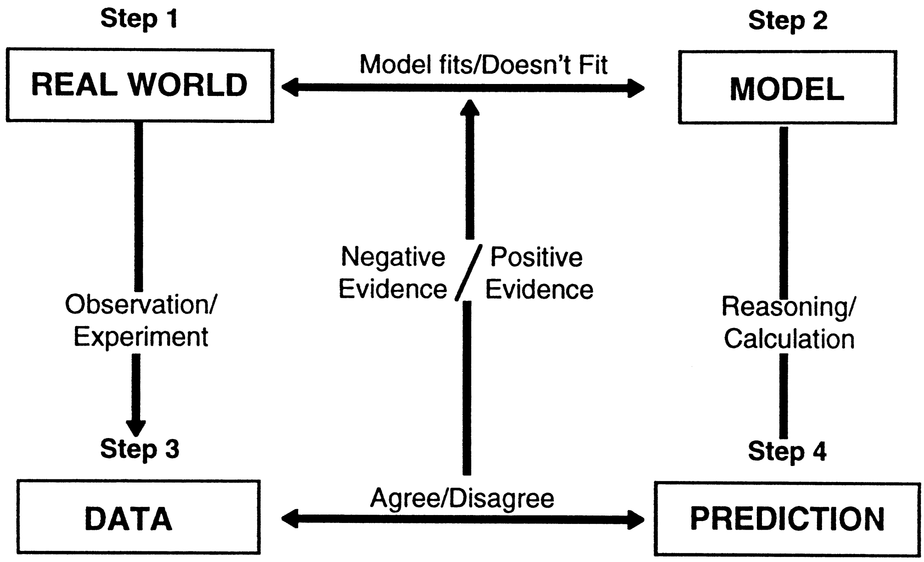

Figure 1. Giere's (1991) diagrammatic representation of the interaction between reasoning, theory, and argument in the development of scientific ideas.

making generalizations from observations of the world through induction. There is the process of establishing what counts as data, through conducting and checking observations and experiments. Then deductions are made from the conjectured theory through reasoning and calculation. The extent to which the data agree or disagree with the prediction then needs to be examined—a process that is rarely straightforward. Rather than a single theory or conjecture to be checked, it is often the case in science that there are two (or more) competing theories. Then the key activity of scientists is evaluating which of these alternatives does, or does not fit with available evidence, and hence, which presents the most convincing explanation for particular phenomena in the world. As Siegel (1989) argued, the central project of science is the search for reliable knowledge, albeit within a limited domain. To achieve this, scientists hold a central core commitment to evidence as the ultimate arbiter between competing theories. Such a commitment, which is basic to science, should therefore be a feature that science education should seek to illuminate strongly.

So far we have considered aspects of the epistemological processes of science. Over the last few decades there has been an increasing awareness of the social processes that are also involved in the production of scientific knowledge as public knowledge. Science is a social practice and scientific knowledge the product of a community. New knowledge does not become public knowledge in science until it has been checked through the various institutions of science. Papers are reviewed by peers before being published in journals. Claims made in published papers are scrutinized and criticized by the wider community of scientists; sometimes experiments are repeated, checked, and alternative interpretations are put forward. In this process of critical scrutiny argument plays a central role. In presenting and evaluating arguments, scientists are influenced by factors beyond those internal to science (such as those represented by the features in Giere's diagram), factors such as scientists' social commitments, values, and by the wider culture of ideas and technological capabilities in society at the time (Woolgar, 1988).

The centrality of argument in science is also shown by the fact that some disputes can take years to resolve (Collins & Pinch, 1993) and that, in some cases, resolution is never achieved. Rarely are differences between theories resolved through single, critical experiments. Much more often careful collating and sifting of evidence is undertaken over an extended period of time until there is enough evidence to mount a strong argument for, or against, competing theories so that certain schools of thought become "interpretively dead." A good example of this process was the way the theory of plate tectonics became accepted after many years of being viewed skeptically by the community of geologists. We see a similar phenomenon enacted in the controversy and argument that surrounds the process of establishing whether BSE ("mad cow" disease) can be transmitted to humans.

It is also important to recognize that these arguments can take place at different levels: first, within the mind of the individual scientist when struggling to design an experiment or to interpret data; second, within research groups where alternative directions for research program are considered in light of the group's theoretical commitments and empirical base; third, within the scientific community at large, through interactions between competing positions at conferences or through journals; and fourth, in the public domain where scientists in a contested field expose their competing theories through the media.

Through this discussion of science as the production of socially constructed knowledge, we have indicated that discursive practices play a central role in establishing knowledge claims. Observation and experiment are not the bedrock on which science is built, but rather they are the handmaidens to the rational activity of generating arguments in support of knowledge claims. But it is on the basis of the strength of the arguments (and their supporting data) that scientists judge competing knowledge claims and work out whether to accept or reject them.

THE PLACE OF ARGUMENT IN SCIENCE EDUCATION

The question that now needs to be asked is what use is argumentation theory to education and to science education in particular? In responding to this question, we would wish to argue that the claim "to know" science is a statement that one knows not only *what* a phenomenon is, but also *how* it relates to other events, *why* it is important, and *how* this particular view of the world came to be. Knowing any of these aspects in isolation misses the point.

Therefore, in learning science, students, as well as having the opportunity to learn about the concepts of science, must also be given some insight into its epistemology, the practices and methods of science, and its nature as a social practice through studies of science-in-the-making, whether historical or in contemporary practice. In constructing our case for the centrality of argument to learning *about* science, we now consider the role that argument should play in developing students' understanding of these components of science in turn. Finally, we discuss the importance of an understanding of argumentative practice within science for the public understanding of science.

The main point we wish to make is that, if we intend to show the socially constructed nature of scientific knowledge, we must give a much higher priority than is currently the case to discursive practices in general and to argument in particular. Being able to present coherent arguments and evaluate others, particularly those reported in the media, is important if students are to understand the basis of the knowledge claims with which they are confronted. Also, in our contemporary, democratic society it is critical that young people receive an education that helps them to both construct and analyze arguments relating to the social applications and implications of science (Dewey, 1916; European Commission, 1995). (This point will be developed further in a later section.)

Developing Conceptual Understanding

Because science involves a process of social construction of knowledge, this means that the terms, the models, and ways of seeing the world agreed upon by scientists are human products—they are not directly perceived from nature. Giving learners access to these "ways of seeing" requires more than giving them access to phenomena. It means inducting learners into the particular ways of representing the world used by scientists and socializing them into adopting the conceptual tools of that culture. Through this process learners are introduced to a new language to represent and to describe the world around them, a language that enables them to portray the world in new ways—a world inhabited by new entities such as genes, chromosomes, electric fields, atoms, and ions.

This process of enculturation into science comes about in a very similar way to the way a foreign language is learned—through its use. Students need opportunities not just to hear explanations being given to them by experts (teachers, books, film, computer programs), but they also need to practice using the ideas themselves to gain confidence in their use, and through this process develop a familiarity with, and understanding of, scientific practices and ways of thinking. Over the last few decades there have been studies undertaken that highlighted the importance of talk in enabling students to develop their understanding of scientific ideas. Seminal work was undertaken by Barnes (1977) and Barnes and Todd (1977). More recently, Lemke (1990) and Sutton (1992) have presented a clear argument for the process of induction of learners into the language of science. Ways of achieving this have been explored in science classrooms in this country and elsewhere. The rise of constructivist learning approaches in science led to an emphasis on discussion and group work in science lessons (CLIS, 1987; Driver, 1987, Duit, Goldberg, & Neidderer, 1992) and the literature on constructivist teaching continues to be an important source of information about appropriate strategies for promoting discussion and argument in order to develop students' conceptual understanding.

In science, we contend that there is a mounting body of evidence that approaches to the teaching and learning of science, based on conceptual challenge and the presentation of anomalous data, are of themselves ineffective (Chinn & Brewer, 1998; Cosgrove, Osborne, & Carr, 1984; Dreyfus, 1990). Rather, it is our view that conceptual change is dependent on the opportunity to socially construct, and reconstruct, one's own personal knowledge through a process of dialogic argument. Such occasions, rare as they are, do occur in science lessons when students are given the opportunity to tackle a problem in a group, or where, in a whole class situation, the teacher orchestrates a discussion to identify different lines of thought and invites students to evaluate these and move toward an agreed outcome. Moreover, it is these opportunities that provide the students themselves with the important task of working out reasoned arguments, and hence, give them practice in developing the skills for themselves.

Developing Investigative Competence

As noted earlier, practical work and, more recently, investigative work have high priority in UK science classrooms. Observation of lessons indicates that much of the time spent on such practical work is devoted to carrying out practical procedures themselves (Newton, Driver, & Osborne, 1999). If science is to be taught from the perspective of the social construction of knowledge, then there are important discursive processes that also need to be incorporated into practical and investigational work. Consideration needs to be given to the purpose of the experiment to be carried out. What would be an appropriate design to address this question? What methods would give reliable data? Once the data have been collected then alternative interpretations need to be considered. It is at this point, in particular, where students need to appreciate that scientific theories are human constructs and that they will not generate a theory, or reach a conclusion, by deduction from the data alone. Instead, they need to postulate possible interpretations and then examine the arguments for each in the light of evidence that is available to them. Practical or experimental work in science thus requires much greater attention, and time, to be given to the processes of planning and interpretation; again, processes that require argument.

Understanding the Epistemology of Science

It is not only important that students use language to understand the concepts or theories of science, it is also important that they appreciate the basis for these knowledge claims. It is only through argument between competing theories about multiple interpretations of events that students can be brought face to face with evaluating how decisions between competing claims can be made (Monk & Osborne, 1997). In short, if the consideration of evidence and argument are to play a central role in developing an understanding of the epistemology and science, science education must move from the singular account of the world it provides to offering *plural interpretations* of phenomena. Kuhn (1992) argued:

> Only by considering alternatives—by seeking to identify what is not—can one begin to achieve any certainty about what is. (p. 64)

The findings of Deanna Kuhn's research on argumentation with a 160 individuals, from ninth graders to mature adults, suggest that the majority of individuals display an epistemological naiveté in their argumentative skills. In reasoning, she found that individuals display a range of errors such as "false inclusion"—the co-occurrence of antecedent and outcome being taken as evidence that the antecedent is causally implicated in the outcome; the failure to use exclusion—a method essential to scientific reasoning as it allows the elimination of extraneous factors from consideration; the domination of affirmation over negation—that is, the presence of something was seen as more important than its absence; and a tendency to dismiss factors as irrelevant thus eliminating the potential for disconfirming evidence. Somewhat dishearteningly, she found that school made no difference after the end of junior high school. This finding led her to conclude, as we do likewise, that remediation would only be offered by the opportunity to engage in argumentative dialogue as only this "externalises argumentative reasoning and offers the exposure to contrasting ideas and the practice that may facilitate its development."

Koslowski (1996), critiqued Kuhn's work for presenting subjects with reasoning exercises that are theoretically impoverished and highly circumscribed: for instance, presenting implausible evidence that the speed of a car is dependent on the presence of a muffler. Whereas without a supporting mechanism, subjects who cannot perceive a causal theory for such conclusions are likely to reject, or at least hold in abeyance, the conclusions to be drawn from such data. Confronted with evidence that undermines only the covariation component, rather than the causal mechanism, the normal human response is not to relinquish beliefs for which there is no self-evident replacement mechanism. The findings from her research suggest that individuals have greater capabilities to use accepted reasoning skills than Kuhn would acknowledge. But, as she pointed out, developing expertise requires a process of bootstrapping between theory and evidence as considerations of theory or mechanism constrain data, and data in turn, constrain, refine, and elaborate theory—all of which require practice in the process of constructing reasoned argument for "explanations are not evaluated in isolation; they are judged in the context of rival accounts."

It is in this process that the teachers also have an important role to play; for example, in pointing out different possible interpretations and requiring students to consider the evidence for each. This is a function that is usually fulfilled in lessons after small groups have had opportunities to explore their own positions. The teacher then has the demanding task of orchestrating a reflective discussion in which the different positions are explained, then compared and contrasted, and decisions are made as to which offers the best interpretation. Making such steps explicit in teaching leads to clarification of the norms by which scientists make rational decisions between alternative hypotheses and begins the process of *establishing the norms of scientific argumentation.*

Understanding Science as a Social Practice

Finally, if students are to appreciate science as a social practice, then it is important that they consider how scientists have made progress in the past and continue to do so today. To gain this understanding students will need to be exposed to information about the actual practices of scientists, how particular problems in science were resolved *in the past,* and how current disputes are being addressed *at present.* Through case studies of the way advances in science have been made in the past, and consideration of competing theories (such as the disputes about the heliocentric view of the solar system, the circulation of the blood, or the discovery of oxygen), students can come to appreciate the role of argument in establishing knowledge claims by following the path of the arguments of others within the social and historical context of their time.

When it comes to the consideration of contemporary issues and disputes, which we regard as essential for any education about science, then students can be given opportunities to explore their own arguments for different positions and thus develop the confidence and skills in argument that are necessary in making life decisions and contributing as citizens to a democratic society, a position that is elaborated in what follows.

Argument and the Public Understanding of Science

Young people of school age are part of the public. They exercise their economic and lifestyle choices. They are also at an age when they tend to be questioning and critical about aspects of the society in which they live.

Here we put forward two reasons why an education in the skills of argument in science is important. First, there are many areas of public science-based policy in which the public has a legitimate voice. Many of these issues, such as air quality and traffic management, use of fertilizers on crops, xenotransplantation, genetic engineering of foods, are complex. The science underlying the issues may not be straightforward and often uncertain. For there may be empirical uncertainty due to lack of data (e.g., global warming), pragmatic uncertainty due to lack of means to investigate the problem (e.g., predicting earthquakes), and theoretical uncertainty due to a lack of a mechanism (e.g., BSE). There is some encouraging evidence, however, that, when given opportunities to consider carefully prepared information about socioscientific issues in groups, members of the public are able to come to reasoned conclusions (Doble, 1995). Coming to an independent, informed view on a range of matters does, however, place a great demand on the public. Nevertheless, what is apparent is that the public will build up an awareness of the trustworthiness of different sources of information (Giddens, 1990; Wynne, 1996). This is a process that could be enhanced educationally by giving students opportunities to consider the range of information sources available on particular issues together with opportunities to consider the grounds for confidence in the different sources. To ask critically of reports about the origin of evidence, whether the evidence is simply correlational or whether there is a plausible theoretical mechanism, whether the results are reproducible, whether they are contested, or about the authority of the scientific source are all essential interrogatory tools for developing a critical engagement with science. From a combination of such information about the science, and a consideration of the trustworthiness of sources, it is hoped that students would be able to develop more informed views about matters that are of current scientific and social relevance to all of us.

A second reason for the importance of argumentation for the public understanding of science relates to providing the public with a more authentic image of what is involved in scientific inquiry. As we pointed out earlier, many studies have shown that most young people and adults view scientific knowledge as emerging from observation and experiment, being fixed for all time and of certain status (Driver et al., 1996; Larochelle & Desautels, 1991; Lederman, 1992). By contrast, the science that is impinging on the lives of people in today's society is often still contested; for example, whether genetically engineered plants should be grown without restriction, the causes of global warming, and the role of artificial fertilizers in the rise of cancers. This raises the issue of how young people and the public at large understand why it is that scientists do not agree about such issues. Is it that some scientists are incompetent—and is that why there are differences of opinion? Could it be that some scientists are biased in their perspective, due to their personal or employment commitments? Neither of these possibilities reflect well on scientists when the public expects science to produce certain answers. Yet, as Gregory and Millar (1998) pointed out:

> . . . while science is in-the-making, the "right answer" is unavailable to everyone including the scientists, and anyone who claims to know it deserves public scepticism if not distrust. In such cases, the scientific literacy enterprise, in terms of knowledge or understanding is beside the point (p. 243)

What is rarely appreciated by the public, therefore, is that rather than being a weakness, dispute lies at the very heart of science. For it is through the process of exposing different interpretations and checking them against available evidence that scientists, and eventually the public, gain confidence in the knowledge claims that are made. Argument is thus the mechanism of quality control in the scientific community. Understanding argument, as used in science, is therefore central to any education *about* science.

RESEARCH ON ARGUMENT IN SCIENCE LESSONS

Having advanced our case for the role of argument in science lesson, we now consider what is known about the process of argumentation in science classroom environments. To what extent does argument aid the development of conceptual understanding? What is its contribution to students' understanding of investigational practice? What do we know about students' ability to argue and what difficulties do they experience with argument? Is there any evidence that argumentation skills can be enhanced? These are all questions that prior research has addressed.

Over the past few decades a number of influential projects have promoted the importance of discourse in classroom learning and have pointed to the significance of cooperative and collaborative group work (Barnes & Todd, 1977; Cowie & Ruddock, 1988, 1990; Ruddock, 1983). While general advice concerning how to structure successful discussion and argument can be found in the literature (e.g., Dillon, 1994; Johnson & Johnson, 1994), this has not been situated within the specific context of the science classroom. There is now an emerging literature, mostly but not exclusively from North America, which is focusing on the processes of discussion and argumentation in science classrooms. In this section, we first describe and discuss this literature in terms of what it says about the role and conduct of argument in addressing three emphases in science teaching: developing conceptual understanding; developing investigational capability; and developing an understanding of scientific epistemology. Second, we consider what is known about students' difficulties with scientific argument. Finally, all of these aspects are of central importance for the consideration of contemporary socioscientific issues and the development of "scientific literacy." Hence, we review what insights studies of students engaged in decision-making and discussion of socioscientific issues offer about the development of argumentative reasoning.

Developing Conceptual Understanding

The focus of the educational studies reviewed in this section is on the use of argument in the development of students' conceptual understanding. The key assumption of this work is that a study of the discourse in science classrooms can provide information about how conceptual scientific knowledge is constructed by students (Eichinger, Anderson, Palinscar, & David, 1991; Jiménez-Aleixandre, Bugallo-Rodríguez, & Duschl, 1997; Lemke, 1990; Mason, 1996; Pontecorvo, 1987). Some studies documented the discourse of groups of students and their interaction with the teacher and provide a subjective interpretation of the cognitive and social processes involved as students develop understanding (Driver, 1989; Driver et al., 1994). Other studies used theoretical schemes to identify features of the discourse. Some, such as the schemes evolved by Pontecorvo (1987) and Alexopoulou and Driver (1997), are analytical and illustrate the different types of discourse moves used by students in discussing conceptual problems in science. Such analyses, which focus on providing a profile of specific discourse moves, however, fail to capture the coherence of an argument as a social product constructed by the group. A more holistic method of analysis is required to capture this feature. Here, Toulmin's model has been used to good effect; for example, by Jiménez-Aleixandre et al. (1997). In this study the discussions of groups of students about a genetics problem set in a practical "real life" context were transcribed and analyzed in terms of the elements of Toulmin's model. This made it possible to represent arguments as group productions and to illustrate features of their structure (e.g., the arguments were very limited in complexity, often warrants were not made explicit, and conceptual confusion affected the quality of the arguments). Jiménez-Aleíxandre et al. also identified aspects of the arguments that could not be represented using Toulmin's scheme; for example, epistemic operations (e.g., causal relations, explanation procedures, analogies, predictions) and the influence of school culture on the arguments produced. What the study did achieve was to make explicit the difficulties students encounter in marshaling evidence, drawing on their conceptual understanding of the topic, and composing arguments in support of scientific knowledge claims.

Developing Investigational Capability

A number of studies have focused on student discussion while the students were engaged in laboratory investigations over extended periods of time. The purpose of the studies has been to understand the processes by which students solve scientific problems within a conceptual area that requires practical investigation. Interest in student performance in this area is based on the view that the process of inquiry is central to developing an understanding of some of the epistemic and methodological tools used by scientists to establish extant and new knowledge.

A substantial descriptive study was reported by Richmond and Shriley (1996). They studied the discourse of six groups of four students during the planning, execution, and interpretation of student-designed experiments in a grade 10 science class over a 3-month period. The course was designed around a case study of the 19th century cholera epidemic in London, and introduced students to the nature of scientific detective work as well as to basic concepts of cell biology. In justifying their approach, the investigators argued that:

> . . . two elements are essential if students are to become scientifically literate—that is, if they are to understand and make effective use of scientific tools and ideas in their execution and interpretation of experiments and in their discourse with others. First, there must be an opportunity for them to develop these tools and see their usefulness across a variety of problem-solving situations. Secondly, they must have the opportunity to see how these tools may be used to construct ideas about scientific processes and then to construct models or theories based on those ideas. (p. 840)

One of the goals of their study was that students should construct arguments for collecting and using data in a scientifically acceptable form, including their ability to identify a problem, construct a testable hypothesis, design an experiment, collect data, and recognize the implications of the results.

The investigators analyzed students' understanding and participation on two dimensions, a conceptual dimension and a social dimension. They considered the interplay between these dimensions in interpreting students' ability to construct arguments as the program of work proceeded. They noted that, at the beginning, students were not able to construct arguments relating to procedural aspects of carrying out their investigations. They had difficulty differentiating between a problem and a hypothesis, understanding the value of controls, and distinguishing between their results and what the observations meant (conclusions). They noted also that, early on in the study, students concentrated on procedural issues with little concern for understanding the conceptual basis of the problem at hand. In general, as a result of the extended program, the investigators reported that levels of student engagement with the problems rose and arguments became more sophisticated. They also noted how the progress of the groups was a product of cognitive and social factors and depended to a great extent on the style of the group leader. This finding serves to emphasize of the importance of social context and the need to develop an understanding of the social rules necessary for "successful" discourse.

Druker, Chen, and Kelly (1997) also provided an analysis of science students' arguments in the context of solving practical performance tasks. The tasks used in their study involved electrical "mystery boxes." Students cooperated in pairs to work out, through empirical tests, what the electrical components in a set of boxes might be. The students' actions and discussion were documented and analyzed using Toulmin's argument framework and as a result a range of types of errors in students' arguments were identified.

Developing an Understanding of Scientific Epistemology

Whereas the two studies just described are essentially descriptive in nature, the research reported by Herrenkohl and Guerra (1995) examined an intervention study designed to improve the *quality* of argumentation employed by students when engaged in investigations. Two classes of fourth grade students from one school were involved in the study that was conducted over a period of 12 teaching days while the students were engaged with a hands-on, inquiry based curriculum unit on "structure and balance." The purpose of the intervention was to engage students in "performances of understanding" in science. To promote this, in the case of both classes, the "rules" of scientific discourse and inquiry were made explicit to the children. Three discourse practices were focused on: monitoring comprehension; coordinating theories (and predictions) with evidence; and challenging others' perspectives and claims. In one of the classes the teacher explained these practices and reminded the children about them each day. The teacher did the same in the second class, but in addition, the children were assigned sociocognitive roles designed to help them monitor each others' reports as they conducted their work. The roles were: checking reports for statements of predictions and theory; checking reports for a clear summary of results; and checking that theory is supported by evidence in reports and, if not, generating alternative accounts. Children took turns in practicing these roles. The oral reports given to the class by the children were recorded and the discourse moves were analyzed. There was clear evidence that, in the class in which the children were assigned roles, the reports from the children included a larger number of the target discourse moves than for the other class. Thus, these findings suggest that, not only is it important to inform students of the norms of scientific argument, but, if students are to assimilate these norms, they also need the experience of rehearsing them for themselves.

Students' Difficulties with Argument

The findings from literacy research indicates that, in general, students are poor at presenting arguments "for and against" or presenting different points of view on the same issue. To address this concern, teachers have been encouraged to pose tasks within an oppositional framework (e.g., debates or arguments for or against in a discussion group). Boulter and Gilbert (1995), however, argued that this oppositional structure, and the polarized language that ensues, can be a problem. Furthermore, they suggested that "an inclusive—rather than oppositional language has more connection with personal experience." This connected language (they argue), which has been identified in the speech of women, operates through listening rather than striving to gain the right to initiate; through "rapport" talk, involving telling what you are thinking, rather than "report talk (exhibiting knowledge and skill)" (p. 97).

A second issue that is worthy of note is the difficulty that students have with constructing argument. Drawing on a wide literature relating to science education, Zeidler (1997) identified the following five reasons for fallacious argumentation—essentially the common errors in students' arguments in science and the reasons for them:

1. *Problems with validity*—students fall into the trap of affirming the consequent and are more likely to affirm a claim if they believe the premises to be true rather than false, despite warrants contrary to their beliefs.
2. *A naive conception of argument structure*—students tend to have a confirmation bias and select evidence accordingly with little attention paid to disconfirming data.
3. *The effects of core beliefs on argumentation*—arguments that are consistent with students' beliefs are more convincing than those that are counter to their beliefs. This weakness compromises students' ability to evaluate counterevidence and criticism.
4. *Inadequate sampling of evidence*—students are not sure what constitutes convincing evidence and tend to jump to conclusions before enough data are available;

their lack of functional understanding of probabilistic information and statistics is also a barrier here.

5. *Altering the representation of argument and evidence*—students do not necessarily consider only the evidence that is presented to them, but make additional assertions about the context of the problem, or even introduce inferences that go beyond the boundaries of the evidence presented and that introduce bias in the outcome.

Chinn and Brewer (1998), in a recent study, argued that students have a set of eight responses to anomalous data choosing either: to ignore the data; to reject it outright; to exclude the data by declaring it to be irrelevant to their field of study; to hold the data in abeyance by deciding that there is insufficient data to determine the outcome or too many uncertainties associated with it; to reinterpret the data by arguing that the causal explanation is significantly different from that proffered by the scientist; to modify their theories peripherally by arguing that its effects are minor rather than major; and, finally, to express uncertainty about the data itself. In only 8 of the 168 cases in their study did students modify their views as a consequence of evidence contradictory to their previously held beliefs.

Both Zeidler (1997) and Chinn and Brewer (1998) reminded us, in their concluding discussions, that scientific thinking is complex and messy and that the reasoning of scientists themselves is often subject to the same kinds of problems listed above. Inducting students into the norms of scientific argument is therefore an idealistic activity; norms may be accepted by the community of scientists but can be overlooked in practice. Yet, making students aware of both how they, and scientists, respond to contradictory claims will provide important insight into the social processes internal to scientific argument.

Socioscientific Issues in Decisionmaking

The rationale for the development of students' skills of decisionmaking about socioscientific issues is presented by researchers in terms of the promotion of scientific literacy.

As Geddis (1991) argued, "Students have to understand the rational basis for their action, and for this to occur they have to work their way through issues until they arrive at a consistent, acceptable position which can be defended persuasively and which takes other points of view into consideration" (p. 170). Furthermore, it has been argued that being able to arrive at a view based on reason and evidence develops intellectual independence (Munby, 1980). Norris (1997) was more cautious, suggesting that full intellectual independence is an unattainable goal, which occupies a status equivalent to the holy grail of science education. Nevertheless, he argued that science education should seek to reduce the epistemic distance between hearing a claim to scientific knowledge and believing that claim to be warranted. In short, modes of argumentation and the epistemology of science are an important component of any education that seeks to enhance scientific literacy.

Studies of science classrooms over several decades have indicated that—far from students being given opportunities to "work their way through issues"—in most classrooms, even those addressing socioscientific issues, it is teachers who do the talking and structure the arguments (Cross & Price, 1996; Geddis, 1991). To address this issue it is critically important that participative methods are developed to engage students themselves in the processes of thinking and discussion in lessons. Discussion of socioscientific issues requires a range of skills to analyze issues and work toward a decision. Many of these have been identified in the literature (Cross & Price, 1992; Ratcliffe, 1996). These include:

1. Understanding argument—being able to distinguish between observation and theory; appreciating the meaning of implications, assumptions, and inferences; and clarifying beliefs and opinions distinguishing them from evidence.
2. Understanding the epistemological basis of scientific knowledge—appreciating the role of conceptualization; understanding the conjectural nature of theory; distinguishing between evidence and theory while being able to coordinate the two; and recognizing the influence of theory on observation and vice versa.
3. Being able to find out about the science relevant to the issue under consideration—conducting literature searches; reading for understanding; and undertaking practical investigations where required.
4. Distinguishing between questions which have a scientific base and questions which relate to other types of knowledge (e.g., ethical, economic, legal questions).
5. Recognizing personal and social values and perspectives that impact on decision-making in science.
6. Evaluating evidence from different perspectives and avoiding confrontational interactions.

A few studies have been undertaken to investigate the discursive processes involved when students engage in discussion about socioscientific issues. A major study was undertaken by Solomon (1992) into the discussion of science-based social issues presented on television. This was a descriptive study that explored how groups of 17–18-year-old students responded in self-led informal discussions following the viewing of selected video programs. The programs featured a number of socioscientific issues including kidney donation, nuclear power, and genetic counseling. From the analysis of the transcripts of the discussions a number of features of the way discussions progressed were identified. Discussions were frequently initiated with a *framing discourse*, a period when students talked through what they had seen and raised matters for discussion. A sequence of *negotiation and persuasion* tended to follow when students exchanged opinions. In this phase it was rare for students to base a case on a logical argument, rather they attempted to persuade each other through the use of examples and empathy with the situation. In some cases, the groups then began to *make broader moral judgments* based on the position they had reached in the particular case. Finally, in some cases, students would advance a *personal strategy* for dealing with the social issue. This study was based on informal discussions with little support or structuring from the teacher. However, Solomon commented that the quality of the discussions improved as students gained experience in conducting them (although no indication was given in the study as to how such a judgment was made).

A number of studies have been conducted that have involved a form of intervention to enhance the *quality* of discussion and argument about socioscientific issues. In a small-scale case study, Geddis (1991) documented the nature of class discussion with a teacher who is teaching about social issues (acid rain). After studying an initial lesson, Geddis provided constructive feedback to the teacher indicating he was making authoritative assertions without presenting the students with the evidence or arguments in support of the claims being made. The teacher was then encouraged to consider the evidence that was necessary to substantiate the claims made. In subsequent lessons, the teacher did enable the students to explore different perspectives on the problem and the possible reasons for these. This research suggests that teachers are inexperienced at managing discussions which enable different viewpoints to be explored and supported, but that coaching in the classroom can be effective for redirecting teacher behavior.

Another interesting contribution offered by Kuhn, Shaw, and Felton (1997) is an investigation in which the purpose of the research was to test the hypothesis that engagement in thinking about a topic enhances the quality of reasoning about that topic. Pairs of subjects (both adults and adolescents) were invited to engage in a series of dyadic discussions on a topic (capital punishment). In comparison with control groups, the quality of the reasoning used by the subjects who had engaged in these discussions (as judged using a hierarchical set of categories to evaluate the quality of the arguments) was significantly enhanced. The type of improvements that were noted included an increase in the range of arguments used, a shift from simple one-sided to more complex two-sided arguments, and, for the adults, being able to place arguments in a broader framework of alternatives. The intervention involved five dyadic discussions with different people over a period of 5 weeks. Significantly, a further study employing a shorter intervention was not found to promote change, indicating that enhancing the skills of argument requires an extended program.

Finally, in a study designed specifically to enhance the decisionmaking processes of secondary school students engaged in discussions about socioscientific issues, Ratcliffe (1996) developed a six-step framework for decisionmaking to guide the deliberation of the student groups. The steps in the framework were: considering options; identifying criteria in choosing an option; checking the available information; considering each option; making a decision between the options; and reflecting on the decisionmaking process. Students undertook a series of decisionmaking activities as part of their science lessons over a period of a few months. Analyses were undertaken of changes in the quality of the decisionmaking processes used (based on a set of level criteria). Overall, the level of decisionmaking of the groups increased as a result of the intervention. It was noted, however, that for students who had already developed thoughtful decisionmaking strategies, peer discussion enhanced these through argument. In cases where less developed strategies were used by students, peer discussion did not bring about reasoned argument. In the Ratcliffe study the intervention did not require a significant input from the class teachers. Therefore, it is possible that, particularly for the less successful groups, greater enhancement in students' ability to develop their arguments could be brought about if teachers were able to intervene and coach groups in their deliberations. It is recognized, however, that many science teachers do not have such skills in their pedagogical repertoire, and that such a course of action would have major professional development implications.

EVIDENCE FROM THE FIELD

As an introductory phase of our own research into argumentation in science lessons, we thought it would be important to determine the extent to which young people are currently given opportunities to develop skills of argument in science lessons in the UK. In 1997, two of the present investigators, therefore, conducted a pilot study that undertook a systematic observation study of 34 science lessons in secondary schools in the Greater London area involving classes of students between the ages of 11 and 16 years (years 7–11). We were interested to find out the extent to which discussion, debate, or argumentation activities are used in regular science lessons. To do this, we developed and used an observation schedule to record student activities and the nature of student–teacher interactions throughout each lesson at 30-second intervals. The results, which are described and commented on in detail elsewhere (Newton, Driver, & Osborne, 1999) are in keeping with other major studies of teacher–pupil interactions in science lessons (Lemke, 1990; Sumfleth & Pitton, 1997). They indicate, among other things, that very little opportunity is given by teachers for students to discuss ideas in groups, or for whole class discussions about the interpretation of events, experiments, or social issues. In the 34 lessons there were only two cases in which the teacher set a group discussion task and these discussions lasted less than 10 minutes each. The dominant form of interaction in the classrooms was teacher talk. Where opportunities were given for students to work in groups, for example, on practical tasks, these were rarely organized in such a way as to encourage substantive discussion of the science involved. Instead, student talk focused on procedural aspects of the practical work. In cases in which the teacher did give students opportunities for discussion, little guidance was given on how to undertake it effectively and the student groups observed had some difficulties in managing the social aspects of the discussion.

To explore teachers' views on the role of discussion, we also interviewed them about the range of teaching strategies they use and asked for their comments on the use of discussion. The general impression was that teachers do see the value of discussion for students' learning. However, they acknowledged that managing discussion effectively is challenging and that they have few general strategies to give structure to discussion work, either in small groups or in whole class settings.

The main message we draw from this preliminary study is that there is a general lack of pedagogical expertise among science teachers in organizing activities in which students are given a voice. The barrier to teachers changing their practice does not seem to be their views of the mechanisms of learning, rather it is the lack of technical, pedagogical skills. Hence, a research and development program which would target specific approaches to enhancing the discursive involvement of students in science lessons could make an important contribution to promoting argument in the science classroom.

CONCLUSIONS: IMPLICATIONS FOR RESEARCH ON ARGUMENTATION IN TEACHING SCIENCE

A number of major points relating to argument in science lessons emerged from the literature and from our preliminary research.

First, it is apparent that current classroom practices give little opportunity for young people to develop their ability to construct arguments. The research of Kuhn (1992) is telling in that it shows that there is little progress in young people's skills of argument beyond primary school. We see this as a reflection of the normal classroom environment failing to provide opportunities for practice (rather than interpreting the lack of change in terms of psychological development).

Studies, however, do provide evidence that skills of argument can be enhanced. Practice, by itself, has been shown to lead to improved argumentation, although it is clear that such practice needs to be quite substantial if gains are to be made. Intervention studies designed to support students in conducting arguments have produced encouraging results. Furthermore, it appears that, not only do students need to develop an awareness of the nature and structure of arguments, but their performance is additionally enhanced if they are able to monitor their involvement in group activities.

The major barrier to developing young people's skills of argument in science is the lack of opportunity offered for such activities within current pedagogical practices. If students are to be given greater opportunities to develop these skills, then this will require a radical change in the way science lessons are structured and conducted. Ways will have to be found to organize lessons so that the students themselves participate actively in thinking through issues and developing their own arguments. In other words, students need to be given a greater voice in lessons.

The fact that this does not happen in science lessons in the UK at the moment may be partly a reflection of the pressure that science teachers are under to "cover the National Curriculum." In our study, teachers also commented that there is a need for better resources to support such group work. We suspect, however, that although these may be contributory factors, the main reason lies in the limitations of teachers' pedagogical repertoire and their limited understanding of the nature of science. Our observations and interviews with science teachers suggest that few teachers have the necessary skills to effectively organize group and class discussions and, hence, they lack confidence in their ability to successfully manage sessions devoted to argumentation and discussion in the classroom. Consequently, such activities rarely, if ever, take place.

If, as has been discussed in this article, argumentation has a central role to play in science and in learning *about* science, then its current omission is a problem that needs to be seriously addressed. For in the light of our emerging understanding of science as social practice, with rhetoric and argument as a central feature, to continue with current approaches to the teaching of science would be to misrepresent science and its nature. If this pattern is to change, then it seems crucial that any intervention should pay attention not only to ways of enhancing the argument skills of young people, but also to improving teachers' knowledge, awareness, and competence in managing student participation in discussion and argument. Given that, for good or for ill, science and technology have ascended to a position of cultural dominance, studying the role of argument in science offers a means of prying open the black box that is science. Such an effort would seem well advised—both for science and its relationship with the public, and the public and its relationship with science.

We are grateful for the thoughtful comments on an earlier draft of this paper provided by John Leach.

REFERENCES

Alexopoulou, E., & Driver, R. (1997). Small group discussions in physics: peer interaction modes in pairs and fours. Journal of Research in Science Teaching, 33(10), 1099–1114.

Atkinson, P., & Delamont, S. (1977). Mock-ups and cock-ups: The stage management of guided discovery instruction. In P. Woods & M. Hammersley (Eds.), School experience: Explorations in the sociology of education. London: Croom Helm.

Barnes, D. (1977). Talking and writing in science lessons. Cambridge Journal of Education 7(3), 138–147.

Barnes, D., & Todd, F. (1977). Communication and learning in small groups. London: Routledge & Kegan Paul.

Billig, M. (1987). Arguing and thinking: A rhetorical approach to social psychology. Cambridge: Cambridge University Press.

Binkley, R. W. (1995). Argumentation, education and reasoning. Informal Logic, 17(2), 127–143.

Blair, J. A., & Johnson, R. H. (1987). Argumentation as dialetical. Argumentation. 1, 41–56.

Boulter, C. J., & Gilbert, J. K. (1995). Argument and science education. In P. S. M. Costello & S. Mitchell (Eds.), Competing and consensual voices: The theory and practice of argumentation. Clevedon, UK: Multilingual Matters.

Chinn, C. A., & Brewer, W. F. (1998). An empirical test of a taxonomy of responses to anomalous data in science. Journal of Research in Science Teaching, 35(6), 623–654.

Claxton, G. (1991). Educating the enquiring mind: The challenge for school science: Harverster, UK: Wheatsheaf.

CLIS (Children's Learning in Science) (1987). Approaches to teaching. Leeds: Centre for Studies in Science & Mathematics Education.

Cohen, I. B. (1952). The education of the public in science. Impact of Science on Society, 3, 67–101.

Collins, H., & Pinch, T. (1993). The Golem: What everyone should know about science. Cambridge: Cambridge University Press.

Cosgrove, M., Osborne, R., & Carr, M. (1984). Children's intuitive ideas on electric current and the modification of those ideas. Aspects of Understanding Electricity, 247–256. Kiel: IPN.

Cowie, H., & Rudduck, J. (1988). School and classroom studies. Volume 2: Learning together—working together. London: BP Educational Service.
Cowie, H., & Rudduck, J. (1990). Co-operative learning traditions and transitions. Volume 3: Learning together—working together. London: BP Educational Service.
Cross, R. T., & Price, R. F. (1992). Teaching science for social responsibility. St. Louis, MO: St. Louis Press.
Cross, R. T., & Price, R. F. (1996). Science teachers' social conscience and the role of controversial issues in the teaching of science. Journal of Research in Science Teaching, 33, (3), 319–333.
Dewey, J. (1916). Democracy and education. New York: Macmillan.
Dillon, J. T. (1994). Using discussion in classrooms. Buckingham, UK: Open University Press.
Doble, J. (1995). Public opinion about issues characterised by technological complexity and scientific uncertainty. Public Understanding of Science, 4, 95–118.
Donnelly, J., Buchan, A., Jenkins, E., Laws, P., & Welford, G. (1996). Investigations by order: Policy, curriculum and science teachers' work under the Education Reform Act. Nafferton, UK: Studies in Science Education.
Dreyfus, A. (1990). Applying the "cognitive conflict" strategy for conceptual change—some implications, difficulties and problems. Science Education, 74(5), 555–569.
Driver, R. (1987). Theory into practice: A constructivist approach to curriculum development. In P. Fensham (Ed.), Development and dilemmas in science education. London: Falmer Press.
Driver, R. (1989). The construction of scientific knowledge in school classrooms. In R. Millar (Ed.), Doing science: Images of science in science education. London: Falmer Press.
Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. Educational Researcher, 23(7), 5–12.
Driver, R., Leach, J., Millar, R., & Scott, P. (1996). Young people's images of science. Buckingham, UK: Open University Press.
Druker, S. L., Chen, C., & Kelly, G. J. (1996). Introducing content to the Toulmin model of argumentation via error analysis. Paper presented at NARST meeting, Chicago, IL.
Duit, R., Goldberg, F. & Niedderer (Eds). (1992). Research in physics learning: theoretical issues and empirical studies. Proceedings of an international workshop. Kiel: IPN.
Duschl, R. A. (1990). Restructuring science education: The importance of theories and their development. New York: Teachers College Press.
Eichinger, D. C., Anderson, C. W., Palincsar, A. S., & David, Y. M. (1991) An illustration of the roles of content knowledge, scientific argument and social norms in collaborative problem-solving. Paper presented at the AERA meeting, San Francisco.
European Commission (1995). White paper on education and training: Teaching and learning—towards the learning society (white paper). Luxembourg: Office for Official Publications in European Countries.
Fuller, S. (1997). Science. Buckingham, UK: Open University Press.
Giddens, A. (1990). The consequences of modernity. Cambridge: Polity Press.
Geddis, A. (1991). Improving the quality of classroom discourse on controversial issues. Science Education, 75, 169–183.
Giere, R. N. (1991). Understanding scientific reasoning (3rd ed.). Forth Worth, TX: Holt, Rinehart & Winston.
Gregory, J., & Miller, S. (1998). Science in public: Communication, culture and credibility. New York: Plenum Press.
Hanson, N. R. (1958). Patterns of discovery. Cambridge: Cambridge University Press.
Herrenkohl, L. R., & Guerra, M. R. (1995). Where did you find your theory in your findings? Participant structures, scientific discourse, and student engagement in fourth grade. Paper presented at AERA annual meeting.
Hunt, J. A. (1994). STS teaching in Britain. In K. T. Boersma, K. Kortland, & J. van Trommel (Eds.), Proceedings of the Seventh IOSTE symposium, Enschede, The Netherlands.
Jiménex-Aleixandre, M. P., Bugallo-Rodríguez, A., & Duschl, R. A. (1997, March). Argument in high school genetics. Paper presented at the National Association for Research in Science Teaching, Chicago, IL.

Johnson, D. W., & Johnson, R. T. (1994). Collaborative learning and argumentation. In P. Kutnik & C. Rogers (Eds.), Groups in schools. London: Cassell.

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

Kress, G., Ogborn, J., Jewitt, C., & Tsatsarleis, B. (1998). Rhetorics of the science classroom: A multimodal approach. London: Institute of Education.

Krummheuer, G. (1995). The ethnography of argumentation. In P. Cobb & H. Bauersfeld (Eds.), Emergence of mathematical meaning. Hillsdale, NJ: Lawrence Erlbaum.

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

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

Kuhn, D., Shaw, V., & Felton, M. (1997). Effects of dyadic interaction on argumentative reasoning. Cognition and Instruction, 15(3), 287–315.

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

Lakin, S., & Wellington, J. (1994). Who will teach the ‘nature of science’? Teachers’ views of science and their implications for science education. International Journal of Science Education, 16, 175–190.

Larochelle, M., & Desautels, J. (1991). ‘Of course, it’s just obvious’: Adolescents’ ideas of scientific knowledge. International Journal of Science Education, 13(4), 373–389.

Latour, B. W., & Woolgar, S. (1986). An anthropologist visits the laboratory. In B. Latour & S. Woolgar (Eds.), Laboratory life: The construction of scientific facts (pp. 83–90). Princeton, NJ: Princeton University Press.

Lederman, N. (1992). Students’ and teachers’ conceptions of the nature of science: A review of the research. Journal of Research in Science Teaching, 29(4), 331–359.

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

Marttunen, M. (1994). Assessing argumentation skills among Finnish university students. Learning and Instruction, 4, 175–191.

Mason, L. (1996). An analysis of children’s construction of new knowledge through their use of reasoning and arguing in classroom discussions. Qualitative Studies in Education, 9(4), 411–433.

Millar, R., & Driver, R. (1987). Beyond processes. Studies in Science Education, 14, 33–62.

Millar, R., & Osborne, J. F. (Eds.) (1998). Beyond 2000: Science education for the future. London: Nuffield Foundation.

Monk, M., & Osborne, J. (1997). Placing the history and philosophy of science on the curriculum: A model for the development of pedagogy. Science Education, 81(4), 405–424.

Munby, A. H. (1980). Analysing teaching for intellectual independence. In H. Munby, G. Orpwood, & T. Russell (Eds.), Seeing curriculum in a new light: Essays from science education. Toronto: OISE 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. (1997). Intellectual independence for nonscientists and other content-transcendent goals of science education. Science Education, 81(2), 239–258.

Norris, S. P., & Phillips, L. M. (1994). Interpreting pragmatic meaning when reading popular reports of science. Journal of Research in Science Teaching, 31(9), 947–967.

Nott, M., & Smith, R. (1995). ‘Talking your way out of it’, ‘rigging’ and ‘conjuring’: What science teachers do when practicals go wrong. International Journal of Science Education, 17(3), 399–410.

Peters, R. S. (1966). Ethics and education. London: George Allen & Unwin.

Pontecorvo, C. (1987). Discussing for reasoning: The role of argument in knowledge construction. In E. De Corte, H. Lodewijks, R. Parmentier, & P. Span (Eds.), Learning and instruction: A publication of the European Association for Research on Learning and Instruction (vol. 1, pp. 71–82). Oxford: EARLI.

Putnam, H. (1981). Why reason can’t be naturalized. Synthese, 52(1), 3–23.

Ratcliffe, M. (1996). Adolescent decision-making, by individual and groups, about science-related

societal issues. In G. Welford, J. Osborne, & P. Scott (Eds.), Research in science education in Europe: Current issues and themes. London: Falmer Press.
Richmond, G., & Striley, J. (1996). Making meaning in classrooms: Social processes in small group discourse and scientific knowledge building. Journal of Research in Science Teaching, 33(8), 839–858.
Rogers, E. M. (1948). Science in general education. In E. J. McGrath (Ed.), Science in general education. Dubuque, IA: William C. Brown Co.
Rudduck, J. (1983). The humanities project: An introduction (rev. ed). Norwich: University of East Anglia, School of Education.
Russell, T. L. (1983). Analyzing arguments in science classroom discourse: Can teachers' questions distort scientific authority? Journal of Research in Science Teaching 20(1), 27–45.
Schwab, J. J. (1962). The teaching of science as enquiry. Cambridge, MA: Harvard University Press.
Scott, P., Asoko, H. M., & Driver, R. (1992). Teaching for conceptual change: A review of strategies. In R. Duit, F. Goldberg, & H. Niedderer (Eds.), Research in physics learning: Theoretical issues and empirical studies. Kiel, Germany: IPN
Siegel, H. (1989). The rationality of science, critical thinking and science education. Synthese, 80(1), 9–42.
Siegel, H. (1995). Why should educators care about argumentation. Informal Logic, 17(2), 159–176.
Solomon, J., & Aikenhead, G. (Eds.) (1994). STS education: International perspectives on reform. New York: Teachers College Press.
Solomon, J. (1991). Group discussions in the classroom. School Science Review, 72, 29–34.
Solomon, J. (1992). The classroom discussion of science-based social issues presented on television: Knowledge, attitudes and values. International Journal of Science Education, 14(4), 431–444.
Solomon, J., Duveen, J., & Scott, L. (1992). Exploring the nature of science: Key stage 4. Hatfield, UK: Association for Science Education.
Sumfleth, E., & Pitton, A. (1997). Learning chemistry today—examples related to different groups of learners. In W. Gräber & C. Bolte (Eds.), Scientific literacy (pp. 349–376). Kiel, Germany: IPN.
Sutton, C. (1992). Words, science and learning. Buckingham, UK: Open. University Press.
Taylor, C. (1996). Defining science. Madison, WI: University of Wisconsin Press.
Toulmin, S. (1958). The uses of argument. Cambridge: Cambridge University Press.
Van Eemeren, F. H. (1995). A world of difference: The rich state of argumentation theory. Informal Logic, 17(2), 144–158.
Woolgar, S. (1988). Science: The very idea. Chichester, UK: Ellis Horwood.
Wynne, B. (1996). Misunderstood misunderstandings: Social identities and public uptake of science. In A. Irwin & B. Wynne (Eds.), Misunderstanding science. Cambridge: Cambridge University Press.
Zeidler, D. L. (1997). The central role of fallacious thinking in science education. Science Education, 81, 483–496.