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Supporting and Promoting Argumentation Discourse in Science Education

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INTRODUCTION

The second half of the twentieth century has seen frequent and rapid changes in our understandings of the growth of knowledge and its development. Dynamic reconfigurations have taken place in theories of learning (from an emphasis on the behavioural to a concern with the cognitive and social nature of thinking); in theories of mind (from a belief in *tabula rasa* to a consideration that there may be innate capacities like language syntax); and in theories of knowledge (from the notion that knowledge is cumulative to ideas that knowledge is often reconfigured, adapted and even abandoned). Such changes have led to arguments which would suggest that (a) classroom instruction needs to be centred around students’ active learning and take into account research that demonstrates that students’ prior knowledge is a significant factor affecting learning; and (b) that the focus of student’s work should transcend the declarative to include procedural and strategic knowledge—that is to enable students’ abilities to reason and reflect metacognitively on their own learning and the construction and evaluation of scientific knowledge. Yet an examination of recent policy reports like *Beyond 2000* (Millar & Osborne,
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1999) and Before it's too late (US Dept. of Education, 2000) strongly suggest that science classrooms, school environments and teaching practices, for all intents and purposes, have remained essentially unchanged during this 50 year period. For it is still the teacher, not the student, who continues to be at the centre of educational practices. In particular, it is the teachers and not the students who initiate most of the discourse in the classroom.

Whilst curriculum innovations in science, such as those sponsored by Nuffield in the UK and the National Science Foundation in the USA in the 1960s and 1970s, may have had significant impact on the nature and type of investigational and practical activities, these developments have had little impact on the pattern of interaction and discourse practices of science teachers (Welch, 1979; Lemke, 1990; Scott, 1998). Four decades after Joseph Schwab’s introduction of the idea that science should be taught as an ‘enquiry into enquiry’, and almost a century after John Dewey advocated classroom learning be a student-centred process of enquiry, we find ourselves still struggling to bring such practices to the classroom. Witness the publication of the AAAS edited volume on enquiry (Minstrell & Van Zee, 2000), the recent release of Inquiry and the National Science Education Standards (NRC, 2000) and the inclusion of ‘scientific enquiry’ as a separate strand in the English and Welsh science national curriculum (DfEE, 1999). These three works serve as signposts to an ideological commitment that teaching science needs to accomplish much more than simply detailing ‘what we know’ and establishing a familiarity with the basic techniques of the domain. Equally important, we would argue, is the need to educate our pupils and citizens about how we know and why we believe; e.g., to expose science as a way of knowing (Driver, Millar, Leach & Scott, 1996; Duschl, 1990; Millar & Osborne, 1999). Such a shift requires a focus on (1) how evidence is used in science for the construction of explanations, and (2) on the criteria used in science to evaluate the selection of evidence and the construction of explanations.

A significant insight towards this end that has developed over the last 50 years, and is yet only partially realised at the level of the classroom, concerns the important role language plays in learning and in the design of effective learning environments. A prominent, if not central, feature of the language of scientific enquiry is debate and argumentation around competing theories, methodologies and aims. Such language activities are central to doing and learning science. Thus, developing an understanding of science and appropriating the syntactic, semantic and pragmatic components of its language requires students to engage in practising and using its discourse in a range of structured activities. Only such tasks will support the social construction of knowledge, exposing student thinking and enabling its critical
evaluation by the teacher, the student and his or her peers. Thus, if the structures that enable and support dialogical argumentation are absent from the classroom, it is hardly surprising that student learning is hindered or curtailed. Or, put simply, teaching science as a process of enquiry without the opportunity to engage in argumentation, the construction of explanations and the evaluation of evidence is to fail to represent a core component of the nature of science or to establish a site for developing student understanding.

The purpose of this paper, therefore, is to examine recent research activities taking place around one particular type of language genre, namely argumentation. This we see as central to restoring an emphasis on the epistemic nature of science. Whilst the consideration of the important function language, conversation and discussion have in science learning can be traced back three or four decades (Scheffler, 1960; Bruner, 1961; Lansdown, Blackwood & Brandwein, 1971), it was not until the 1980s that serious discussion of the role of language in science learning began (c.f., Aikenhead, 1991; Gee, 1994; Lemke, 1983; Lemke, 1990; Sutton, 1992). More recently, the field has turned its attention to the discourse of argumentation. We begin the paper by putting forward a few explanations for obstacles to taking up enquiry and subsequently argumentation. This leads us to the view that there are inherent or implicit assumptions about learning environments that support or undermine enquiry and argumentation. Therefore, we next review recent research on cognitive and social perspectives on the development and growth of knowledge in the fields of psychology and philosophy for the purposes of framing and establishing the structure, function and purpose of argumentation in science classrooms.

We then turn to the role of language, discourse and argumentation in science education. Two themes are addressed in our review of this literature. First what should constitute argumentation? As will be seen, there is a tension between the lay perception of argumentation, as war that seeks to establish a winner, which contrasts with a view of argumentation as a social and collaborative process necessary to solve problems and advance knowledge. The second theme, and our principal focus, is concerned with what research says about the classroom conditions that promote, nurture and sustain argumentation practices among students. The paper finishes with a discussion of implications for future research and curriculum development that addresses language and argumentation in science learning environments. First, however, it is important to note that, throughout this paper, we are using the word ‘argumentation’ to denote the process of constructing an argument, and the word ‘argument’ as a referent to the content of argument.
POSSIBLE BARRIERS TO ARGUMENTATION IN THE LEARNING OF SCIENCE

We began the paper by pointing out the lack of impact curriculum innovations focusing on enquiry have had on practice in science education. There are a number of explanations put forward to account for the stasis in teacher-centred pedagogical practices we find in today’s classrooms. For instance, Novak (1977) has attributed the lack of change in the practices of science teaching and learning to our lack of a theory of learning in the 1960s, when science curriculum innovations were first being prepared. Proposals to organize science education around discovery teaching, enquiry teaching, language use and science process skills were executed in advance of any comprehensive understanding of children’s reasoning and cognitive development. An alternative to Novak’s ‘lack of a theory of science learning’ explanation is that the programmatic goals of science education are misplaced. Many years ago, Schwab (1962) lamented the problem of focusing on ‘what we know’, thus making science teaching what he called a ‘rhetoric of conclusions’ rather than an enquiry into enquiry. As Duschl (1990) points out, this emphasis on ‘final form’ science remains unchanged. A more recent rhetorical analysis of the science teacher’s task sees it as one of persuading his or her students of the validity of the scientific world-view (Ogborn et al., 1996; Millar, 1998; Osborne, 2001). In such a context, research has shown that whole class discourse is, more often than not, dominated by a teacher-led structure that focuses on the ‘facts’ and follows the pattern of teacher Initiation, student Response, and teacher Evaluation (called I-R-E by Mehan, 1979; or triadic dialog by Lemke, 1990). Such a discourse strategy may contribute to students learning facts through the linguistic processes of selection, modification, recontextualisation and co-constructing the entities that populate the ‘ontological zoo’ of science (Edwards & Mercer, 1987). However, it does not function well when the goal of instruction is to promote reasoning skills, ‘doing’ science, or learning about science. Students are commonly given less than a second to formulate their answers (Rowe, 1974) which then consist of single words or short phrases rather than a reasoned argument consisting of an extended student contribution of dialogic argument often associated with uncertainty and tentativeness. Fundamentally such dialogue has limited educational value and maintains the power-relations that support and structure classroom life. Thus, the fact that the teacher, rather than the student asks the questions ensures that the locus of enquiry is circumscribed and controlled by the teacher and hence not understood by the student. In contrast, an a priori requirement for a context that supports a discourse of argumentation requires
the consideration of plural accounts of phenomena and a context which permits dialogical discourse – a discourse which is the natural product of any community of enquirers and one which sees all members as, at least in principle, equal. And, moreover, it is dialogic discourse which supports the reasoning which promotes the higher order cognitive skills of evaluation and synthesis rather than recall and comprehension.

Finally, and perhaps most importantly for us, teaching science as an enquiry into enquiry must address *epistemic goals* that focus on *how we know* what we know, and *why we believe* the beliefs of science to be superior or more fruitful than competing viewpoints. For, as one of us (Osborne, 2001) has argued, if science and scientists are epistemically privileged, then it is a major shortcoming of our educational programmes that we offer so little to justify the accord that the scientists would wish us to render unto scientific knowledge. Hence, if the rationale for universal science education lies in its cultural pervasiveness and significance, then attention must be given to explaining why science is considered the epitome of rationality, and why scientific thinking is the dominant paradigm of contemporary society. In short, to exposing the nature of science and the values that underlie it.

Yet another explanation for the lack of student-centred ‘enquiry into enquiry’ rests on a failure to adopt curriculum and instruction strategies that integrate the social (used here to refer to the discursive modes and contexts by which scientific information and knowledge are communicated and represented) and the cognitive aspects of engaging in scientific enquiry. There now exists a body of research that supports the integration of the social and cognitive dimensions of learning and reasoning (Greeno, 1997). There also exists compelling research that speaks to the importance of establishing structures that enable students to engage with science in classrooms in communities of practice that facilitate modes of discourse which more closely resemble those of the scientific community. In such communities, students would be encouraged to question, to justify and to evaluate their own, and others’ reasoning, enculturating the students as learners into discourse processes that support personal knowledge construction and student metacognition (Brown, Collins, Duguid, 1989; Brown & Campione, 1994; Cobb, 1994; Driver, Asoko, Leach, Mortimer, & Scott, 1994; Wertsch, 1991; Kelly & Crawford, 1997; Polman & Pea, 2001). Forward looking perspectives on new ways to bring enquiry to science classrooms can be found in Minstrell & Van Zee (2000) and National Research Council (2000).

From such a perspective, one critically important task is establishing or engineering a context in which epistemic dialogue and epistemic activities can occur (De Vries *et al.*, 2002). Fundamentally this requires creating the
conditions in which students can engage in argumentation; i.e., to explore critically the coordination of evidence and theory that support or refute an explanatory conclusion, model or prediction (Suppe, 1998). Situating argumentation as a critical element in the design of science learning environments both engages learners with conceptual and epistemic goals and, for the purposes of the practice of formative assessment by teachers, can help make scientific thinking and reasoning visible. Central to our view of the value of argumentation is a conception, proposed by Ohlsson (1995), of discourse as a medium which stimulates the process of reflection through which students may acquire conceptual understanding. For as De Vries et al. (2002) state discourse activities are important because:

In comparison with problem solving activities, they embody a much smaller gap between performance and competence. In other words, the occurrence of explanatory and argumentative discourse (performance) about concepts effectively reveals the degree of understanding of those concepts. Epistemic activities are therefore discursive activities (e.g. text writing, verbal interaction, or presentation) that operate primarily on knowledge and understanding rather than on procedures. (64, emphasis added.)

Our view, then, is that epistemic goals are not to be seen as additional extraneous aspects of science to be marginalized to single lessons or the periphery of the curriculum (Duschl, 2000). Rather, striving for epistemic goals such as the ability to construct, evaluate and revise scientific arguments offers a means of attaining cognitive aims as well. Yet, as Newton, Driver and Osborne (1999) have shown, opportunities for such deliberative dialogue within science classrooms are minimal.

We argue in this review paper that conditions for supporting argumentation are dependent on the use of evidence in the process of building and evaluating explanations. The construction of an explanation requires students to clarify their thinking, to generate examples, to recognise the need for additional information and to monitor and repair gaps in their knowledge. In particular, it requires the construction of an argument that relates models or theories to a body of available evidence. For example, the task of convincing a sceptic that the Earth is a sphere, approximately, or that day and night are caused by a spinning Earth and not a moving Sun, cannot be done without engaging in a dialogue at the core of which lies the construction of argument. Rational belief rests on good reasons which consist of data, warrants and underlying theoretical tenets which acquire epistemic force through critical
evaluation against agreed criteria (Siegel, 1989). It is the role of science education, therefore, to expose the criteria by which such evaluations are made, and explain how those criteria are themselves justified – a task which can only be done if argumentation occupies a central rather than peripheral position in the values of the science educator.

To explain the grounds and warrants for scientific belief is to model the discourse that takes place in scientific communities. Moreover, there now exists ample evidence to suggest that effective science education – that is an education that aims for conceptual and epistemic understanding – requires student engagement in such forms of communication (e.g., Herrenkohl, Palincsar, DeWater & Kawasaki, 1999; Roseberry, Warren & Conant, 1992; Schauble, Glaser, Duschl, Schulze & John, 1995). Hence, scientific enquiry requires immersion into the language, culture, and tools of scientific activity – a language and culture that is grounded in certain logical and epistemological values that make science different from other ways of knowing. We believe that science has particular ways of considering evidence; generating, testing, and evaluating theories; and communicating ideas. Underpinning the work of the scientist is a belief that good theories are empirically adequate and that better theories are more comprehensive than others; good theories are also self-consistent, display original or creative thinking and offer explanatory power and predictive validity (Prelli, 2001). And, as the AAAS, NRC, and English National Curriculum documents on enquiry attest, one critically important goal of science education is to help students participate in and understand the enquiry practices, language genres, and values of science.

FOUNDATIONAL FRAMEWORKS FOR ENQUIRY & ARGUMENTATION

Learning Theory and Theory of Knowledge

Novak’s atheoretical situation no longer exists. Research on cognitive factors like the role of prior knowledge and strategic knowledge and on social and cultural contexts that engage and support language use and learning are helping to redefine our notions and ideas about effective schools and classrooms. Deanna Kuhn (1999), in a review of research on the development of critical thinking skills, shows how our emerging knowledge of children’s intellectual development can be described on three cognitive dimensions. One is ‘metacognitive processes’ (knowing how to learn), the second is ‘metastrategic processes’ (knowing which strategies to deploy), and the third is ‘epistemological framework’ (an understanding of how we know). She argues
that a consideration of these three dimensions can be used to enrich our visions of good practice by offering us multiple aims for the constituents of an effective education. More significantly, an emphasis on metacognition changes the conception of the student from that of a receptor of information to one who is an active constructor of knowledge. In this situation,

(t)o be competent and motivated to ‘know how you know’ puts one in charge of one’s own knowing, of deciding what to believe and why and of updating and revising those beliefs as one deems warranted. To achieve this control of their own thinking is arguably the most important way in which people both individually and collectively take control of their own lives. (Kuhn, 1999: 23)

Robert Glaser (1995), in a major review of how psychology can inform educational practice develops and outlines the components of a coherent learning theory that can inform instruction and illuminates how Kuhn’s approach might be achieved. He identifies 7 research findings (see Figure 1) that inform us about the structure and design of learning environments – aspects of which are further elaborated in How people learn (Bransford, Brown & Cocking, 1999).

Figure 1: Glaser’s Seven Principles of Instruction

1. **Structured Knowledge.** ‘Instruction should foster increasingly articulated conceptual structures that enable inference and reasoning in various domains of knowledge and skill’ (17).

2. **Use of Prior Knowledge and Cognitive Ability.** ‘Relevant prior knowledge and intuition of the learner is ... an important source of cognitive ability that can support and scaffold new learning ... the assessment and use of cognitive abilities that arise from specific knowledge can facilitate new learning in a particular domain’ (18).

3. **Metacognition Generative Cognitive Skill.** ‘The use of generative self-regulatory cognitive strategies that enable individuals to reflect on, construct meaning from, and control their own activities ... is a significant dimension of evolving cognitive skill in learning from childhood onward... These cognitive skills are critical to develop in instructional situations because they enhance the acquisition of knowledge by overseeing its use and by facilitating the transfer of
knowledge to new situations... These skills provide learners with a sense of agency’ (18).

4. **Active and Procedural Use of Knowledge in Meaningful Contexts.** ‘Learning activities must emphasize the acquisition of knowledge, but this information must be connected with the conditions of its use and procedures for its applicability... School learning activities must be contextualized and situated so that the goals of the enterprise are apparent to the participants’ (19, emphasis in original).

5. **Social Participation and Social Cognition.** ‘The social display and social modelling of cognitive competence through group participation is a pervasive mechanism for the internalization and acquisition of knowledge and skill in individuals. Learning environments that involve dialogue with teachers and between peers provide opportunities for learners to share, critique, think with, and add to a common knowledge base’ (19).

6. **Holistic Situations for Learning.** ‘Learners understand the goals and meanings of an activity as they attain specific competencies... Competence is best developed through learning that takes place in the course of supported cognitive apprenticeship abilities within larger task contexts’ (19-20).

7. **Making Thinking Overt.** ‘Design situations in which the thinking of the learner is made apparent and overt to the teacher and to students. In this way, student thinking can be examined, questioned, and shaped as an active object of constructive learning’ (20).

Prominent in the components of effective learning environments identified by Glaser is a recognition of the important role that prior knowledge, context, language and social processes have on cognitive development and learning. These components are centrally important to the process of learning. Such understandings have guided many educational researchers to now conceive of thinking and reasoning as acts that are socially driven (Brown, 1992; Cobb, 1994; Rogoff, 1990), language dependent (Wertsch, 1991), governed by context or situation (diSessa, 2000; Brown, Collins and Duguid, 1989) and involving a variety of tool-use and cognitive strategies (Edelson, Gordin, & Pea, 1999; Kuhn, 1999). Putnam & Borko (2000), in an article that examines the challenges these new ideas about knowledge and learning have for teacher education, summarize these newer conceptions of learning respectively as
cognition as social (in that it requires interaction with others), cognition as situated (in that it is domain specific and not easily transferable), and cognition as distributed (in that the construction of knowledge is a communal rather than an individual activity). The various programmes of research conducted and coordinated by cognitive, social, developmental and educational psychologists now present a more coherent and multi-faceted theory of learning that can inform the design of learning environments (Bransford, Brown & Cocking, 1999). In science education, we interpret this to mean that students must have an opportunity to engage in activities which require them to use the language and reasoning of science with their fellow students and teachers – that is to engage in the construction and evaluation of scientific argument.

**Theory of Knowledge and Science Studies**

Likewise, a more coherent and multi-faceted theory of knowledge is emerging from the science studies disciplines and it, too, has significant implications for thinking about the structure and use of argumentation in science learning environments. The influence of history of science and sociology of science on philosophy of science this past century has been both dynamic and controversial. In addition to the dynamic changes in psychology, the twentieth century has also been witness to exciting theoretical developments in the life and Earth sciences that have provided alternative ‘model-based’ images of science which challenge the deterministic hypothesis-testing images suggested by the physical sciences about the nature of science. Collectively referred to as ‘science studies’, the confluence of the three disciplines (history, philosophy and sociology of science), and the shift of attention from physical sciences to life and earth science, has brought about substantive challenges to the rationality and objectivity of scientific knowledge and innovative responses. A thorough review of the genesis of science studies and subsequent ‘Science Wars’ is beyond the scope of the present paper. (Interested readers are directed to Ruse (1979; 1999) and Kitcher (1985).) What is relevant for a consideration of argumentation in science education is the turn to the cognitive sciences made by many philosophers to combat the perspectives from the sociology of science which are apsychological and to preserve the role of reasoning and evidence in a theory of knowledge.

Indeed, both Giere (1988) and Kitcher (1993) develop epistemologies of science grounded in cognitive views. Kitcher (1993) explicitly distinguishes between cognitive and acognitive accounts of the growth of scientific knowledge in his analysis of the reasoning processes found in major scientific
debates, arguing that the determination and coordination of evidence for the purposes of proposing explanations is an argumentation process involving both cognitive and social dynamics. Giere (1988), while not explicitly making references to social processes in the growth of knowledge, certainly hints at the prospect that science as a way of knowing functions within both a social and cognitive matrix. In a later paper, Giere (1996) does go much further in linking cognition and knowledge growth to social conditions in his critical response to Allison Gopnick’s (1996) thesis that the child possesses innate cognitive abilities that match those of the scientist. Kitcher (1993), in turn, sets out a formal framework to account for how social institutions, social relationships and personal aspirations can affect positively the growth of knowledge.

Stronger alliances between cognitive and social schemas of science can also be found in Hull (1988), Thagard (1994), and Longino (1994). For instance, in his Science as a process, Hull examines the intellectual battles between two competing research traditions in systematics, i.e., the study and interpretation of taxonomic classifications, demonstrating how a concern for status among the scientists can foster conceptual evolution. Thagard, too, (1994) argues that cognitive and social schemas are complementary and that either purely cognitive or social explanations of science are inadequate. He writes: ‘from a naturalistic perspective, we can appreciate science as a product of individual minds and as a product of complex social organizations’ (italic in original, p 630). In arguing his case, Thagard presents 4 schemas for explaining belief change that we present in Table 1. From this analysis, where the components of a perspective that integrates the cognitive and social aspect of science are presented in the fourth column, we can see the important role that mental representations, beliefs, and interests all have in scientific enquiry.

Likewise, Longino (1994), in an effort to counter antirational images of science, offers an objective framework based on the social negotiation of scientific knowledge that sets out 4 conditions a scientific community must meet in order for a consensus to qualify as knowledge:

1. There must be publicly recognised forums for the criticism of evidence, of methods, and assumptions about reasoning.

2. There must be uptake of criticism. The community must not merely tolerate dissent, but its beliefs and theories must change over time in response to the critical discourse taking place within it.

3. There must be publicly recognised standards by reference to which theories, hypotheses, and observational practices are evaluated, and by
appeal to which criticism is made relevant to the goals of the inquiring community.

4. Finally, communities must be characterised by equality of intellectual authority.

Table 1: Schemas for Explaining Belief Change

<table>
<thead>
<tr>
<th>Logical</th>
<th>Cognitive</th>
<th>Social</th>
<th>Integrated Cognitive/Social</th>
</tr>
</thead>
<tbody>
<tr>
<td>The scientists had a set of previous beliefs</td>
<td>The scientists had a set of mental representations that included a set of previous beliefs and interests</td>
<td>The scientists had previous beliefs and interests</td>
<td>The scientists had a set of mental representations that included a set of previous beliefs and a set of interests</td>
</tr>
<tr>
<td>The scientists employed logical methods</td>
<td>The scientists' cognitive mechanisms included a set of mental procedures</td>
<td>The scientists had social connections and power relations</td>
<td>The scientists' cognitive mechanisms included a set of mental procedures &amp; The scientists had social connections and power relations</td>
</tr>
<tr>
<td>When applied to the previous beliefs, the logical method implies a set of acquired beliefs</td>
<td>When applied to the mental representations and previous beliefs, the procedures produce a set of acquired beliefs</td>
<td>Previous beliefs and interests and social connections and power relations lead to acquired beliefs</td>
<td>When applied to the mental representations previous beliefs, in the context of and social connections and power relation, the procedures produce a set of acquired beliefs</td>
</tr>
<tr>
<td>So the scientists adopted the acquired beliefs</td>
<td>So the scientists adopted the acquired beliefs</td>
<td>So the scientists adopted the acquired beliefs</td>
<td>So the scientists adopted the acquired beliefs</td>
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</table>

(From Thagard (1994), italics in original)
These guidelines, as Grandy (1997) suggests, provide a framework for the design of classroom learning environments that seek to promote epistemic communities within which it is possible to explicitly teach the nature of science through the integration of the cognitive and social dimension of learning. For they provide a framework which recognises the importance of establishing criteria for the evaluation of evidence, the public display of reasoning and values that govern the behaviour of the participants in the discourse. Hence, we see Thagard's schemas, Longino's four conditions and Glaser's seven principles as useful theoretical frameworks for guiding the framing and implementation of argumentation in science learning environments and for justifying its importance to science education.

CONDITIONS FOR ENQUIRY AND ARGUMENTATION LEARNING ENVIRONMENTS

In this next section we turn to a review of research on argumentation processes and its significance, and examine the literature from two perspectives. One issue is: what should constitute or count as argumentation. This relates to the function and role of argumentation in education. From an educational perspective there exists a tension between the common notion of argumentation as an adversarial activity, as opposed to the view that we would wish to promote – that argument is the substance of any meaningful discourse that seeks to generate improved knowledge and understanding. The second issue we review is: what research indicates are the classroom and curriculum conditions that promote, nurture and sustain argumentation practices among students. Here, particular attention is given to group dynamics and to contexts for supporting enquiry and discourse.

Argumentation Processes and Goals

Argumentation has three generally recognized forms: analytical, dialectical, and rhetorical (van Eemeren et al., 1996). The application of analytical arguments (e.g., formal logic) to evaluate science claims is extensive and pervasive. The capstone event of applying argumentation to the sciences is perhaps Hemple-Oppenheimer’s Deductive-Nomological Explanation Model (Hemple, 1965) wherein the argumentation form is used as an account to establish the objectivity of scientific explanations. Toulmin’s (1958) examination of argumentation was one of the first to challenge the ‘truth’ seeking role of argument and instead push us to consider the rhetorical
elements of argumentation. For Toulmin, arguments are field dependent. As, in practice, the warrants and backings used to make claims are shaped by the guiding conceptions and values of the field. For in science, what counts as evidence, and the theoretical assumptions driving the interpretations of that evidence, are consensually and socially agreed by the community - an idea recognized by Schwab who saw the teaching of science as an investigation of the guiding conceptions that shape enquiry.

Likewise, case studies of scientists engaging in scientific enquiry show that the discourse of science-in-the-making involves frequent use of dialectical argumentation strategies (Dunbar, 1995; Latour & Woolgar, 1979; Longino, 1994; Gross, 1996). Research in the sociology of science (Collins & Pinch, 1994; Taylor 1996) has also demonstrated the importance of rhetorical devices in arguing for or against the public acceptance of scientific discoveries. In short, the practice of science consists of a complex interaction between theory, data and evidence. The rationality of science is founded on the ability to construct persuasive and convincing arguments that relate explanatory theories to observational data. Thus science requires the consideration of differing theoretical explanations for a given phenomenon, deliberation about methods for conducting experiments, and the evaluation of interpretations of data. Clearly then, argumentation is a genre of discourse central to doing science (Lemke, 1990; Kuhn, 1993; Siegel, 1995; Kelly & Crawford, 1997; Kelly, Chen & Crawford, 1998; Suppe, 1998; Newton, Driver and Osborne, 1999; Driver, Newton & Osborne, 2000). If students are to be persuaded of the validity and rationality of the scientific world-view then the grounds for belief must be presented and explored in the context of the science classroom. In short, as argued elsewhere:

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. (Driver, Newton & Osborne, 2000, emphasis in original)

Such an aim requires the opportunity to consider plural theoretical accounts and the opportunity to construct and evaluate arguments relating ideas and their evidence. For as Kuhn (1992: 164) argues, ‘only by considering alternatives – by seeking to identify what is not – can one begin to achieve any certainty about what is.’ Not to do so will leave the student reliant on the authority of the teacher as the epistemic basis of belief leaving the dependence on evidence and argument – a central feature of science – veiled from
inspection. Or, in the words of Gaston Bachelard (1940), the essential function of argument is that, 'two people must first contradict each other if they really wish to understand each other. Truth is the child of argument, not of fond affinity.' Indeed, Ogborn et al. (1996) show elegantly how one of the fundamental strategies of all science teachers is the creation of difference between their view and their students’ view of phenomena. For without difference, there can be no argument, and without argument, there can be no explanation. Within the context of science, dedicated as it is to achieving consensus, argument, then, is a core discursive strategy, and a sine qua non for the introduction of argument is the establishment of differing (i.e., plural) theoretical accounts of the world. This is not to suggest that argument is something which is unique to science for argument plays a similar function in many other disciplines. Rather, our intent is to show that argument is as central to science as it is to other forms of knowledge and, therefore, cannot be ignored in any science education.

Solomon (1998, 2001), however, cautions science educators to think about the differences between discussion, argument and debate, particularly in the context of teaching controversial issues confronting society. Discussion, she asserts, is trying to see all sides of an issue whilst argument is choosing sides and trying to defeat the other. Such a view is, we believe, overly simplistic. Arguments are the mortar holding together the evidence and theories out of which scientific explanations are constructed, and explanations are the substances of the conceptual ideas under construction. Explanation building is full of detours, dead ends and fallacious arguments but the essence of dialogic discourse and the moral basis on which it rests is not the intellectual vanquishing of others but the search for knowledge and understanding.

Mitchell (1996) helps in this matter by distinguishing between two types of argument – regular and critical arguments. Regular arguments, she states, are rule-applying arguments that put forward applications of theories that are not in themselves being challenged. Such arguments are generally predictive and a central feature of the work of scientists. In contrast, critical arguments do challenge the theories and ideas but have as a fundamental goal the refinement of existing theories or introduction of alternative ideas and not the defeat of another. In the moral community that is science, personal conflicts and aspirations are always secondary to the advancement of knowledge.

We must remember, therefore, that initial efforts at engaging children in argumentation will require setting ground rules to avoid, for instance, ad hominem arguments that attack the person and not the ideas (Dillon, 1994). Such preliminary attempts to initiate argumentation practices will also require modelling and practising the standard inductive (argument by example,
argument by analogy, argument by causal correlation) and deductive (argument from causal generalization, argument from sign, syllogisms) forms of argument. Worth mentioning at this point is the research one of us (Duschl, Ellenbogen & Erduran, 1999) has conducted, showing that children do seem to have a natural tendency to engage in such inductive and deductive forms of argument when a sound context is provided.

Thus, like Cohen (1995) we would contend that to see argumentation as war is an ineffective and inappropriate metaphor for promoting dialogic discourse – a metaphor that must be explicitly refuted and countered when initiating the contexts for argument in the classroom. The alternative is to envision argumentation as a process that *furthers* enquiry and not as a process that ends enquiry. Thus, alternative and more apposite metaphors for Cohen (1995) include argumentation as diplomatic negotiation, argumentation as growth or adaptation, metamorphosis, brainstorming, barn raising, mental exercises for the intellect or roundabouts on the streets of discourse. Science as a way of knowing does seek consensus; but, more often than not, progression in scientific thinking involves the use of critical arguments and processes that are more akin to diplomatic negotiation than to conflict.

Harvey Siegel (1995) in an article titled ‘Why should educators care about argumentation?’ takes the position that if one ideal of education is the development of students’ rationality, then we must be concerned not only with how students reason and present their arguments but also with what students come to consider as criteria for good reasons. Siegel sees argumentation as the way forward because of the correlation between the ideal of rationality and the normative concerns and dimensions of argumentation and argumentation theory. He writes, ‘Argumentation...is aimed at the rational resolution of questions, issues, and disputes. When we engage in argumentation, we do not seek simply to resolve disagreements or outstanding questions in any old way ...Argumentation...is concerned with/dependent upon the goodness, the normative status, or epistemic forcefulness, of candidate reasoning for belief, judgment, and action.’ (162, emphasis in original). Thus the second concern within the introduction of argumentation is the necessity to model effective arguments in science, to expose the criteria which are used for judgement (such as parsimony, comprehensiveness and coherence) as to why some arguments are considered better than another. For instance, given two arguments to explain the 24 hour rotation of the Sun and stars, why do we pick the argument that it is the Earth that is moving rather than the Sun and stars.

Critically important to argument is allowing learners to have the time to understand the central concepts and underlying principles (e.g., the ‘facts’) important to the particular domain (Goldman et al., in press). In other words,
a necessary condition for good arguments is a knowledge of the ‘facts’ of a field as otherwise there is no evidence which forms the foundation of a scientific argument. Alternatively, students must be provided with a body of ‘facts’ as a resource with which to argue (Osborne, Simon & Erduran, 1999). However, argumentation does not necessarily follow from merely knowing the ‘facts’ of a field. Equally important is an understanding of how to deploy the ‘facts’ to propose convincing and sound arguments relating evidence and explanation. Herein lies the need for learners to develop strategic and procedural knowledge skills that underpin the construction of argument.

In summary, the challenge is to provide teachers and students with tools that help them build on nascent forms of student argumentation to develop more sophisticated forms of scientific discourse (Duschl et al., 1999; Osborne, Erduran, Simon & Monk, 2001). Such tools need to address the construction, coordination, and evaluation of scientific knowledge claims. Equally important, as Siegel (1995) argues, is the need to address the development of criteria that students can employ to determine the goodness, the normative status, or epistemic forcefulness of reasons for belief, judgement, and action.

What we have shown here is that the central role of argumentation in doing science is supported by both psychologists (Kuhn, 1993) and philosophers of science (Siegel, 1995; Suppe, 1998) as well as science education researchers studying the discourse patterns of reasoning in science contexts (Bell & Linn, 2000; Driver, Newton & Osborne, 2000; Kelly, Chen, & Crawford, 1998; Kelly & Crawford, 1997; Lemke, 1990). Designing learning environments to both facilitate and promote students’ argumentation is, however, a complex problem. For the central project of the science teacher is to persuade his or her students of the validity of the scientific world-view. Conceived of in this manner – as a rhetorical project – the consideration of plural enterprises simply undermines the science teacher’s task and threatens the learner’s knowledge of ‘the right answer’. Moreover, normal classroom discourse is predominantly monologic and it is difficult for teachers to transcend such normal modes of discourse. Therefore, changing the pattern and nature of classroom discourse requires a change both in the structure of classroom activities and the aims that underlie them – issues that we now explore.

**Conditions for Supporting Argumentation**

Argumentation is fundamentally a dialogic event carried out among two or more individuals. Scientific argumentation we will define as the special case when the dialog addresses the coordination of evidence and theory to advance an explanation, a model, a prediction or an evaluation. Regardless of whether
it is a scientist working on the creation of new knowledge, the application of well-established theories, or a student attempting to comprehend old knowledge the argumentation process is essentially similar – both participants have to construct an argument that justifies the claims they espouse in the light of the evidence that they have to hand. However, a major distinction between the two contexts is that, whereas argumentation is a normative feature of the working context of the practising scientist, it is, as we have argued, a rare feature in the discourse of the science classroom. A central issue for the design of learning environments, therefore, is how to develop opportunities for the discourse practices of science in classrooms to reflect or model the discourse practices and processes employed in science.

Hence, a major element important for engaging learners in argumentation processes in classrooms is establishing effective contexts and conditions for such discourse to take place. At the core of such contexts is the requirement to consider not singular explanations of phenomena but plural accounts. Students must, at the very least spend time considering not only the scientific theory but an alternative such as the common lay misconception, e.g., the view that all objects fall with the same acceleration versus the notion that heavier things fall faster. Such contexts can also include, amongst others, considerations of socio-scientific issues involving the application of science (e.g., the use of animals for drug testing), problem-based learning situations, or computer mediated situations (e.g., the material developed by the WISE project). (Bell & Linn, 2000)

However, the nature of the power relationship that exists between science teacher and student, and the rhetorical project of the science teacher which seeks to establish the consensually-agreed scientific world-view with the student, means that opportunities for dialogic discourse are minimised. The evidence that exists suggests that argumentation is fostered by a context in which student-student interaction is permitted and encouraged. For instance, Kuhn, Shaw & Felton (1997) in testing the hypothesis that engagement in thinking about a topic enhances the quality of reasoning about the topic, found that dyadic interaction between peers significantly increased the quality of argumentative reasoning in both early adolescence and young adults. Eichinger, Anderson, Palincsar & David (1991) found that bringing scientific discourse to the classroom requires the adoption of instructional designs that permit students to work collaboratively in problem solving groups. They see the need to develop classroom cultures that support both ‘democratic norms of responsibility and tolerance and the scientific norms for the construction of arguments based on theory and evidence’ (24). In essence, part of the role of the teacher must be to teach his or her students the social and epistemic ground
rules for engaging in productive dialogic discourse. The findings of our own research work both on teaching argumentation (Osborne, Erduran, Simon & Monk, 2001) and the work we are currently engaged in on exploring what are the requirements for effective teaching of the nature of science would reinforce such arguments (Bartholomew, Osborne & Ratcliffe, 2002).

A review of research on conditions for productive small groups by Cohen (1994) points out that both no guidelines and highly structured guidelines to students can negatively affect the quality of discourse in groups. Another important finding of Cohen’s work is that tasks and activities given to groups must be group activities requiring collaboration. If the task can be executed by an individual, then this will work against the possibility of dialogic discourse between students. Any consideration for bringing argumentation processes to science classrooms must consider the general conditions that serve to support dialogic discourse amongst learners.

Some of the research on discourse points to the importance of establishing procedural guidelines for the students. Herrenkohl, Palincsar, DeWater & Kawasaki (1999) studied the role and value of scaffolding (i.e., guiding and supporting) upper elementary student discussions for the purpose of building theories and models from data. A key factor in the design of the learning environment was ‘fostering a sophisticated epistemology of science by having students experience science as a process of revision’ (451). Students worked in small group and whole class contexts to build and evaluate explanations. The design of the classroom science community was guided by a set of intellectual tools presented to students as ‘three strategic steps in science’: (1) predicting and theorizing; (2) summarizing results; (3) relating predictions and theories to results. The authors view these three steps as thinking practices or intellectual roles that guide students in the construction of scientific arguments linking theory to evidence and, vice-versa. An important scaffolding feature of the research was that procedural guidelines based on co-operative learning precepts were provided to students to help them complete investigations while in small groups. The point is that both epistemological and social structures in the classrooms are important factors for designing inquiry activities that foster argumentation.

In addition to general strategic steps such as recognising the need to listen to others and to justify one’s claims, strategies have also been used to define and support students’ roles in the classroom. Herrenkohl & Guerra (1998) examined the effect on student engagement of guidelines for students who constituted the audience, in addition to guidelines specifying the intellectual roles required by the small groups engaged in activity. The intellectual roles were, once again, predicting and theorizing, summarizing results, and relating
predictions, theories and results. In the treatment group, students received specific audience role assignments for the times small groups reported back to the whole class. The audience role assignments were designed to correspond with the intellectual roles and required students to check classmates’ work. Specifically, students in the ‘audience roles condition’ were directed to develop a ‘question chart’ designed for the purpose of supporting students in addressing the question: ‘What questions could we ask when it is our job to check predictions and theories [or summaries of results or the relations among predictions, theories, and results]? (Herrenkohl & Guerra, 1998: 445-446). On each occasion small group reports were given, the question chart was used and found to be an effective and important scaffold for students taking on the role of audience members in promoting dialogic discourse and higher order intellectual reasoning. Examples of student questions for the question chart provided by Herrenkohl & Guerra are:

**Prediction questions:** What did you guess? What did you hope? Do you think your prediction was right? What might you think your results would be? What did you know? What was your prediction?

**Theory questions:** Why do you think that? How did you know that? What was your theory? What made you think that? Why did you guess that? Do you like your theory?

**Results questions:** What helped you find your results? How did you get that? What were your results? What made that happen? Did your group agree on the results? Did you like what happened?

**Relating predictions, theories and findings questions:** Did what you think was going to happen really happen? Where do you find your theory in your findings? What happened in your theory and findings? What you thought, it is true? Why or why not? Did you find out anything new? Did your predictions come true?

(Herrenkohl & Guerra, 1998: 471-473)

The idea was to have students take classmates group reports and use them as ‘thinking devices’ (Wertsch, 1991). Following the framework developed by Hatano & Inagaki (1991), Herrenkohl and Guerra used the audience role procedures to engage students in (1) asking clarification questions; (2) disputing or challenging others’ perspectives and claims; and, (3) co-ordinating bits of knowledge. Such a focus on listening skills and audience roles is held
to be a critically important element of community discourse (Wertsch, 1991) and here the ‘audience roles [are] designed to get students involved in questioning and commenting on each others’ thinking in science’ (Herrenkohl et al., 1999: 454).

Findings from both Herrenkohl et al. (1999) and Herrenkohl & Guerra (1998) show that using such techniques the students were able to achieve important understandings about the relationship between theory and evidence. The discourse patterns showed that both students and the teacher, when adopting the role of a critical audience, were different in that there were many examples of negotiating a shared understanding, monitoring comprehension, challenging others’ perspectives, and coordinating theories and evidence. The process for obtaining the understanding was not linear but rather iterative as students tried out a diversity of explanations and negotiated features of the theory. Such findings resonate with the work of King who looked at the effect on learning and understanding of the strategies of self-questioning, summarising and note-taking. Both of the former strategies outperformed note-taking, which King (1992) attributed to the metacognitive component of such procedures. However, more fundamentally, we see such processes as requiring a process of internal dialogic argumentation to facilitate the production of an explanation. Thus what aids cognitive development is dialogic argumentation, period.

Another study of argumentation that incorporated scaffolds, in the original sense (i.e., a process that enables ‘a child ...to carry out a task or achieve a goal which is beyond his unassisted efforts’ (Wood, Bruner & Ross, 1976: 90)) is that developed by Bell & Linn (2000). Here the scaffolds are a set of tools found in a computer programme. Further, the context for argumentation is framed around a debate that asks students to support one of two hypotheses for the propagation of light. In this computer-supported learning environment students are required to co-ordinate theory and evidence but do so employing the highly scaffolded context of the Knowledge-Integration-Environment. (See Linn, 2000 for a description of KIE.) In this environment students are presented with two competing theories for the propagation of light and asked to take a stance for one or the other employing a set of evidence and experimental results obtained from computer data files and student investigations. A host of computer tools are made available for students to organize and report arguments for one or the other theories of light. Bell and Linn claim that involving students in building arguments helps achieve knowledge integration and develop in students a view of the nature of science as a dynamic entity.
In another context, Roth, McGinn, Woszczyna & Boutonne (1999) employed a problem-based curriculum model on simple machines to examine whether it was possible to establish a form of legitimate peripheral participation in science discussions of middle school students. They found that a different arrangement of artefacts, social configurations and physical arrangements did contribute to different participant roles and improved levels of participation in group and classroom conversations.

The research reviewed here seems to indicate that it is possible to change the nature and structure of the discourses in science classrooms, and to offer pointers as to how this change might be achieved. Nevertheless, such approaches are not without their problems. Jimenez-Alexandre, et al. (2000), using a problem-based curriculum model on genetics with high school students, found a tension during small group discourse between times when argumentation focused on doing science and when it focused on doing the lesson. They found that while the argumentation discourse employed many instances of linking evidence to theory, there was nonetheless many occasions where students’ conditioning or socialization into school cultures found them doing the lesson and not thinking about doing science (Bloome, Puro & Theodorou, 1989). Rafal (1996), in an investigation of co-construction talk among all girl member groups, also found that participation in small group conversations was linked to the different task orientations the girls in the group held. If a member of the group perceived the task as an individual one, this tended to work against the group co-construction and the fostering of dialogic discourse. Such a finding is consistent with Cohen’s (1994) view that groups need to be given group tasks – group tasks which are fostered by the kind of procedural guidelines developed in the work of Herrenkohl et al. (1999). It is also interesting to note that Rafal also found that group talk provided different and more beneficial access opportunities than those occurring in whole class contexts – that is a wider range of students made significant contributions to the discourse and the co-construction of the group’s understanding.

An interesting extension of this work can be found in that of Barron (2000) who conducted a case study of two contrasting small groups to determine what features of group dynamics contribute to effective coordination or collaboration. Analysing patterns of discourse and behaviour from a high-achieving group and low-achieving group, she found 3 forms of co-ordination taking place in the groups – mutuality in interaction, joint attention, and shared task alignment – and that these features could differentiate and account for the group’s performance. The definition of the forms and markers of high and low achievement are presented in Table 2.
Table 2 Forms and Markers of Co-ordination

<table>
<thead>
<tr>
<th>Forms of Coordination</th>
<th>Markers of Coordination</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Definitions</strong></td>
<td>High Achievement</td>
</tr>
<tr>
<td><strong>Shared Task Alignment</strong></td>
<td>Co-construction of solutions</td>
</tr>
<tr>
<td>Establishment of a collaborative orientation toward problem solving</td>
<td>Reference to other's ideas</td>
</tr>
<tr>
<td></td>
<td>Independent solution paths</td>
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<tr>
<td><strong>Joint Attention</strong></td>
<td>Workbook as centre of co-ordination</td>
</tr>
<tr>
<td>Degree to which attention is jointly focused during solution-critical moments</td>
<td>Joint monitoring of solution</td>
</tr>
<tr>
<td></td>
<td>Workbook as territory</td>
</tr>
<tr>
<td></td>
<td>Individual monitoring</td>
</tr>
<tr>
<td><strong>Mutality</strong></td>
<td>Productive conflicts</td>
</tr>
<tr>
<td>Reciprocity with potential for all members to meaningfully contribute</td>
<td>Transactional responses</td>
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<tr>
<td></td>
<td>Conflicts of insistence</td>
</tr>
<tr>
<td></td>
<td>No response to contributions</td>
</tr>
<tr>
<td></td>
<td>Turn-taking norms respected</td>
</tr>
<tr>
<td></td>
<td>Turn-taking norms violated</td>
</tr>
</tbody>
</table>

(From Baron, 2000: 429)

The above studies are all examples of attempts to connect learners to an environment that supports doing science and using language and thus supports and develops argumentation. In summary, there seem to be two important elements of an environment which support the use of argumentation in school science classrooms. One element is the need to provide students access to plural accounts of phenomena and the evidence that could be used in an argument for one or the other account. Of itself, that is not sufficient. A second required element is a context which fosters dialogic discourse. This we see as requiring the use of techniques such as student presentations and small-group discussions, coupled with guidelines and assistance that support the appropriation of argumentation skills and discourse. The studies above have
set out some specific steps that help guide students in argumentation practices and begin to show the manner in which argumentation can be foregrounded in the science classroom. More importantly, perhaps, the studies reviewed here have clearly demonstrated that argumentative discourse is possible when conditions are right. Nevertheless, like all innovations, such approaches inevitably raise a set of new challenges and issues.

IMPLICATIONS AND ISSUES

Assuming, as the research evidence suggests, that we can establish a context which fosters and develops students use of argumentation, then what can teachers learn by listening to these conversations and how can they foster and improve the quality of argument? Essentially, how can they respond formatively to assist their students and develop their reasoning? How, for instance, can they identify the essential features of an argument? How are they to judge that one argument is better than another? And how should they model arguments of quality to their students? Before we can ask teachers to engage their students in argumentation and use the information they acquire from the process to plan subsequent lessons or evaluate students learning, it is essential to provide some theoretical guidance to answer such questions. Thus, one important line of research is establishing a set of standard methods to analyse both the content and the form of children’s arguments. To date, most investigations of student discourse have relied on either the application of analytical forms of arguments (Kuhn, 1993) or Toulmin’s model for practical arguments (Eichinger, Anderson, Palincsar & David, 1991; Pontecorvo & Girardet, 1993; Bugallo & Jimenez, 1996; Kelly, Chen & Crawford, 1998; Osborne et al., 2001). In these studies, emphasis is placed on the identification and use of the structural features of arguments – that is premises, initial conditions, claims, data, warrants, backings and qualifiers – and the process of argument rather than its content. Such approaches seek to identify the absence or presence of the components of argument and use these to assess their quality. For instance, Osborne et al. have developed a 5 point scale using Toulmin’s framework as a measure of the quality of argument (Osborne, Erduran & Simon, 2001). Such approaches are not without their problems, as the distinctions between the Toulmin components, in particular, whether an item is a component of data, a warrant or a backing, is often not easily resolved and often context dependent. Osborne et al. would contend that the approach they have adopted in their work has sought to minimise and reduce this problem of using the Toulmin framework.
Another alternative avenue has sought to focus on the logic and content of the dialogue for the analysis of argumentation discourse in science classrooms (Goldman, et al., in press; Duschl & Ellenbogen, 2001; Duschl, Ellenbogen & Erduran, 1999) and the underlying presumptions in the argument. For instance, an individual may use an argument based on a singular example, an argument from authority or an argument which refers to an established rule. Walton (1996) has identified 25 categories of argument which are commonly used in the construction of arguments based in what he terms ‘presumptive reasoning’. Such reasoning is rooted in the idea that ‘if the premises are true (or acceptable), then the conclusion does not follow deductively or inductively, but only as a reasonable presumption in given circumstances, subject to retraction if those circumstances should change’ (Walton, 1996:13). Argumentation schemes that focus on presumptive reasoning focus on the evidence and premises a person uses and force the respondent to examine the premises held by the other. Thus, they shift the burden of proof from the individual advancing the claim to the respondent as, in essence, the argument is true until proved otherwise—a kind of legalistic falsificationist framework. Such arguments are apparent during dialectical argumentative exchanges such as those which occur during collaborative small group science investigations, and within assessment conversations (Jimenez-Aleixandre, et al., 2000) and asynchronous computer-supported communication environments (Bell & Linn, 2000) where the discourse is typically focused on one or more advocates’ positions. Using Walton’s schema (Goldman, et al., in press; Duschl, Ellenbogen & Erduran, 1999) for the analysis of small group discourse has suggested that the use of presumptive reasoning can be employed as a framework to analyse students’ argumentation and, hence, is worthy of further consideration and development. Other promising approaches for studying discourse have used linguistic theory to analyse science talk (c.f., Scott, 1998; Gee, 1994; Lemke, 1990).

However, the study of argumentation is a young field that has only emerged in the past decade within the context of science education. Hence, more research needs to be carried out on the tools and pedagogical strategies that can assist teachers and students in both the construction and evaluation of scientific arguments. For example, we need to have a better understanding of strategies to be used with students for reporting and presenting when they complete enquiry investigations – strategies that will both encourage argument and engage all students, such as those developed by Herrenkohl et al. (1999). Perhaps a more fundamental obstacle is the authoritarian nature of science education in which teachers themselves have been encultured. Within a context where the principal aim of school science and undergraduate education is the pre-professional preparation of the next generation of scientists, the
dominant requirement is that students become familiar with the foundations of the scientific canon. For the student, the consequence is an emphasis on establishing a good knowledge and familiarity with the entities that constitute the domain of science and not on their epistemic justification or the nature of the subject itself. Thus most scientists and science teachers have only a minimal knowledge of the history, philosophy and epistemology of their own subject. For instance, simply asking most science students (and many science teachers) what is the justification for the standard scientific explanation of day and night exposes that their sole reason for this knowledge resides in a belief in the epistemic authority of their teacher or textbooks rather than a knowledge of the evidence itself.

Moreover, very few science teachers have ever become fully-fledged members of the scientific community – a process of socialisation which normally requires the opportunity to undertake original research. Thus, not only are science teachers’ knowledge of the nature of science limited by the nature of their own education, but they, themselves, have not been exposed to the normative discourse practices of the scientific community. Replicating or modelling discourse practices within the classroom is, therefore, inherently problematic raising serious issues about how such understanding can be developed by both initial and continuing professional development. Not until pedagogical practices and curricula begin a process of transformation and establishing opportunities for students to engage in enquiry that models authentic practice tracking data to evidence, and evidence to explanations can we expect a transformation in the nature of science classrooms.

We also need a better understanding of the mechanisms that serve as a bridge from the argumentation within a group context to developing individual capabilities with the content of an argument. Whilst we have seen that social structures are important for promoting argumentation, we also need studies that examine the nature of evidence and how students use it to format their enquiries and arguments. Here is where Toulmin’s Argumentation Pattern and Walton’s presumptive reasoning categories can provide guidance on the quality of reasoning. Here, too, is where the epistemological frameworks of Thagard (1994), Longino (1994), Giere (1988) and other philosophers of science can help us design what Grandy (1997) calls epistemic communities and values. For whilst the social dimension of establishing argumentation is important more attention needs to be given to the epistemic nature of the reasoning as well. Students need to develop a sense of the criteria for claiming this evidence or argument is better than that evidence or argument. The studies by Herrenkohl et al. (1999) and Herrenkohl & Guerra (1998) are good examples of the analysis of the quality and use of epistemic reasoning.
More fundamentally, however, much of this work on argumentation is founded in a belief, articulated by Billig (1996), that ‘learning to argue is learning to think’. Given that we now have a body of work which provides some reasonable foundations for (a) the establishment of argument in school classrooms, and (b) a framework for its analysis, an urgent research question for our community is to investigate whether regular use of argumentation in science classrooms does lead to significant gains in conceptual development and cognitive reasoning in science. Such studies could take the form of small case studies with one group of children to larger, more experimental based approaches. Both would be helpful and illuminating. For the discursive nature of argumentation requires both time to undertake the process and time for reflection and consideration of the outcomes. Given the overburdened curricula that currently exist in many countries, few teachers will be prepared to adopt such approaches unless there is evidence that it will have positive cognitive outcomes.

Finally, another dimension worth considering is how inter-textual processes affect scientific discourse and argumentation. Students today have access to many sources of scientific information that transcend the boundaries of the classroom – the Internet, books, magazines, textbooks, lectures, museums, science centres, movies, TV, etc. We need to learn more about how these diverse sources can be incorporated in the argumentation discourse of classrooms. How can the tasks that we develop to promote argumentation encourage students to draw on such evidence and to use it in a critical and reflective manner? In short, can a focus on argumentation be a vehicle for developing distributed modes of learning where the student acquires knowledge from a broader range of sources than those traditionally offered within the hermetic walls of the classroom? Therefore, as well as seeking to understand argumentation within single context domains (e.g., variables that effect the motion of pendulum) situated in the classroom, we should seek to examine the use and development of argumentation across multiple disciplinary contexts (e.g., causes for global warming) that transcend the boundaries of the school science laboratory.

In school science, the enterprise of addressing epistemic connections is about carefully designed learning sequences that engage students in both investigations and colloquia or conversations around the investigations. This idea of colloquia in science classrooms is taken from Lansdown, Blackwood & Brandwein (1971). Grounded in Vygotsky’s theory of learning, that meaning is obtained through language, colloquium are opportunities for ‘speaking together’ that begin with ‘a pooling of observations, getting a collection of facts into the arena, so to speak, to make individuals aware of common data
seen from different viewpoints. This is the beginning of speaking together.’
(Lansdown, et al, 1971: 120) Thirty years on we are beginning to understand
more about the ways of supporting occasions for speaking together in
classrooms, how their quality can be assessed, and what it is such occasions
can do for learning. Nevertheless, there is still much work to be done.

NOTES

1 We recognise that other disciplines share some of these values. However, what distinguishes
science is the application of the combination of this values in determining the worth of any new
idea or theory.
2 The major distinction we would draw here is between scientists engaged in ‘normal’ science—in
the Kuhnian sense of working within an established paradigm deploying what Mitchell has termed
‘regular’ arguments, and research scientists whose work requires critical evaluation of existing
theories or the ideas of other scientists.

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