Epistemic practices and thinking in science

Fostering teachers’ development in scientific argumentation

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Epistemic practices in science education: the case of argumentation

In this chapter, we will review the role of epistemic practices of science in science education, in particular in relation to teachers’ learning of argumentation, an example epistemic practice in science. Epistemic practices in science could involve a range of knowledge production and evaluation processes such as coordination of theory and evidence, and making sense of patterns in data. Epistemic practices in science education refer to those cognitive and discursive activities that engage learners in the knowledge construction and evaluation processes of science. Conventionally in school science, students’ engagement in epistemic practices of science and in argumentation in particular has been scarce. Despite years of reform across the world to improve science teaching and learning, the epistemic aspects of science teaching and learning continue to be of concern to many science education researchers (e.g. Chinn & Malhotra, 2002; Jimenez-Aleixandre, Bugallo-Rodriguez, & Duschl, 2000; Kaya, Erduran, & Cetin, 2012; Kelly & Takao, 2002; Sandoval & Reiser, 2004). Argumentation as the process of justification of knowledge claims with evidence is an instance of epistemic practices of science (Erduran, & Jimenez-Aleixandre, 2007) including the articulation of the role of subject knowledge in science (Cetin, Erduran, & Kaya, 2010).

Why is the inclusion of epistemic practices of science in science education useful? Why should teachers aim to engage learners in epistemic practices of science such as scientific argumentation? First, development of students’ epistemic beliefs and understanding of science will be dependent on how students experience the epistemic activities and norms of science in the classroom (Hennessey, Murphy, & Kulikowich, 2013). If students can develop epistemic understanding they will more effectively engage in self-directed inquiry, and develop deeper conceptual understanding of science. Second, inclusion of epistemic practices of science in
science education brings forth coherence with analyses of science from philosophical perspectives. Contemporary perspectives in philosophy of science (e.g. Giere, 1991; Kitcher, 1988) emphasise that science is not simply the accumulation of facts about how the world is. Science involves the construction of theories that explain how the world may be. In proposing provisional explanations for the underlying causes of phenomena, theories are open to challenge and refutation (e.g. Popper, 1959). Furthermore, science often progresses through dispute, conflict and argumentation rather than through general agreement (e.g. Latour & Woolgar, 1986). Thus, scientists construct a whole range of arguments including arguments about the feasibility of experimental design, the interpretation of evidence and the validity of knowledge claims. Indeed, it is through argumentation, scientific community maintains quality control in science (Kuhn, 1992).

Stephen Toulmin's well-known book titled *The Uses of Argument* has made a significant impact on how science educators have defined and used argument (Toulmin, 1958). Toulmin’s definition of argument (as a system of claims, data, warrants, backings, rebuttals, and qualifiers) has been applied as a methodological tool (e.g. Erduran, et al., 2004; Jimenez, et al., 2000) as well as a heuristic for instructional approaches (e.g. Jimenez, et al., 2000; Kelly & Takao, 2002) and assessment of student work (e.g. Hart, 1998). Another characterisation of argumentation that has been used by science educators is that developed by Douglas Walton (Walton, 1996). Walton’s schemes for presumptive reasoning have been used as a methodological tool in characterising the nature of teachers’ and students’ argumentation in science classrooms (e.g. Castells, Erduran, & Konstantinidou, 2010; Duschl, 2008; Ozdem, Ertepinar, Cakiroglu, & Erduran, 2013). Walton’s argumentation schemes for presumptive reasoning are more concerned about types of arguments.

According to Walton, the justification for presumptive reasoning is that “despite its uncertain and inconclusive nature, it moves a dialogue forward part way to drawing a final conclusion, even in the absence of evidence for proof at a given point” (Walton, 2001, p. 156). Presumptive reasoning does not need to be inductive or deductive, or does not need to be proved to be true. However, it needs to carry a weight of plausibility if an argument is to be accepted. Although Toulmin and Walton frameworks have dominated the science education community’s approach to argumentation in science teaching and learning (Rapanta, Garcia-Mila, & Gilabert, 2013), other approaches have also been used to a lesser extent, such as Perelman and Olbrechts-Tyteca’s characterisation (1969). Erduran (2007) reviewed the various schemes underpinning the methodological aspects of argumentation.

It should be noted that the promotion of argumentation as a key skill is not only of research interest to science educators and cognitive psychologists alike. Inherent in numerous curriculum policy documents around the world, there is now widespread acceptance that students should not only understand scientific knowledge but also how scientific knowledge is produced and justified. Consider for instance the US context where the curriculum standards promote that students determine answers to questions such as, “What counts? What data do we discard? What patterns exist in the data? Are these patterns appropriate for this inquiry? What explanations account for the patterns? Is one explanation better than another?” (NRC, 2000, p. 18).

In this chapter, we trace argumentation as an instance of epistemic practices of science and cognitive skills underlying scientific reasoning. We situate argumentation in relation to research on higher order thinking skills and critical thinking skills, both areas of research that are closely related to the cognitive dimensions of scientific reasoning. We explore these themes in the context of science teachers’ development and in particular with implications for professional development of science teachers in acquiring those cognitive, epistemic and pedagogical skills for effective teaching and learning of argumentation in the science classroom.
Higher order thinking skills (HOT)

The term HOT originated in Bloom’s (1965) taxonomy and refers to seeking common standards to define educational goals and assessment. Bloom’s assumption was that student learning entails different processing levels. Bloom’s original taxonomy (see Krathwohl, 2002 for a review) provided definitions for each of the six major categories in the cognitive domain (ordered from simple to complex), with the assumption that mastery of each category was a prerequisite to mastery of the next, more complex category. The six categories, including action verbs that illustrate each process in parentheses, were the following: knowledge (define, memorise, recall, repeat), comprehension (explain, estimate, identify, paraphrase, review), application (apply, change, illustrate, use), analysis (analyse, differentiate, identify, infer, outline), synthesis (categorise, reorganise, design, develop, rewrite), and evaluation (argue, assess, evaluate, predict, support). Krathwohl (2002) proposed a revision of Bloom’s taxonomy by adding the metaknowledge category to the original categories.

Argumentation is part of the highest category (knowledge evaluation) in the original taxonomy. Along with Krathwohl’s (2002) addition of the metaknowledge criterion to the definition of HOT, cognitive psychologists define argumentation as a higher order thinking skill that requires metacognition (Kitchener, 1983; Kuhn, 1999). Kitchener (1983) argues that in tasks in which individuals are presented contradictory evidence, reasoning involves three levels of cognitive processing: cognitive, metacognitive and epistemic. Cognitive processing, as a first-order processing skill, implies computing, memorising, reading, perceiving, solving problems, and so on. Metacognitive processing involves monitoring the progress of the first-order tasks, and epistemic cognition is the monitoring of the cognitive and metacognitive aspects concerned with knowledge and knowing. As such, epistemic cognition entails reflection about the limits of knowing, the certainty of knowing, and the criteria of knowing to account for complex monitoring.

Metacognitive knowledge was originally defined as knowledge about variables related to a person, task and/or strategy that are believed to affect cognition (Flavell, 1979; Flavell, Miller, & Miller, 2002). In more general terms, it is currently defined as knowledge about one’s own cognition and the control of such cognition by means of monitoring, evaluation, recapitulation, and reflection processes (Barzilai & Zohar, 2012; Brown, 1978; Flavell, 1979; Pintrich, 2002). As this definition indicates, the first part involves declarative knowledge (knowing what), while the second involves procedural knowledge (knowing how). Kuhn (1999, 2000a, 2000b) also perceives argumentation as encompassing metaknowing competence. Such metaknowing is composed of three main types of knowing – metacognitive, metastrategic, and epistemological knowing. Metacognitive knowing mainly refers to declarative knowledge, whereas metastrategic knowing refers to procedural knowledge. Accordingly, metastrategic knowing refers to applying strategy knowledge about what the various thinking strategies can accomplish when pursuing goals, that is, when, why, and how to apply the strategies. Additionally, metastrategic knowing also includes task knowledge (e.g. goals and requirements of tasks), which incorporates the interrelated sub-components of knowing (Kuhn, 1999; Barzilai & Zohar, 2012). Finally, epistemological knowing involves knowing about knowledge in general and in relation to a person’s knowing. Translated into performance, the three types of knowing correspond to know-what, know-how, and know-be skills (Brown & Duguid, 2001; Rapanta, Garcia-Mila, & Gilabert, 2012). In their analysis of argumentation competence in education, Rapanta et al. (2012) propose these types of metacognitive competences as argumentation assessment modes. We present them herein as a guide tool for what teachers should address and should be aware of in their science inquiry classes where epistemic practices of science are enacted.
1 The metacognitive assessment mode, as the know-what skills, is related to the metacognitive aspects of knowing, which, when applied to argumentation, would correspond to what one should know to construct valid informal arguments. These argument skills can be assessed by means of three parameters. The first parameter is the structure of the argument, which refers to how the statements that conform to an argument are connected and how the elements of each statement are organised. Is the argument assessed in terms of its structural quality according to (a) length, (b) complexity, or (c) clarity/coherence? The second parameter is that of conceptual quality. Argumentation is always about a specific subject that may be evaluated in varying degrees based on conceptual quality. Is the argument assessed with respect to its conceptual quality in terms of (a) conceptual relevance, (b) knowledge integration, or (c) creativity? The third parameter is that of epistemic quality. This refers to the degree of the validity of the argument, expressed by a valid relation between the claim and how the claim is supported. Does the argument incorporate (a) pre-defined argument schemes, (b) correct and valid evidence, or (c) explicit relationships?

2 The metastrategic assessment mode, as the know-how dimension of cognitive competence, refers to the implementation of strategies that have some greater influence than other strategies with respect to performance goals. Such understanding can be manifested in argument performance through four strategic assessment constructs. The first construct consists of discourse components that are considered to be especially related to the quality of argumentation, such as (a) warrant/backing, (b) counter-argument/rebuttal, (c) qualifiers/meta, (d) clarification, (e) question, (f) explanation, (g) challenge, (h) evaluation, (i) introduction, (j) example, or (k) hypothesis. The second construct is that of explicit parameters that are related to (a) claims/reasons, (b) evidence, or (c) other. The third construct involves the implementation of certain argumentative strategies that presuppose a high level of metacognitive knowing and the application of certain argument strategies, such as (a) two-sidedness, (b) theory–evidence coordination, (c) use of strategic sequences of moves, and (d) broadening the space of the debate. The final construct distinguishes between assessments related to the distinction of other, non-argument discourse structures, such as (a) narration, (b) explanation, and (c) fallacy.

3 The epistemological assessment mode is related to the epistemological, or know-be, dimension of cognitive performance. In argumentation, this type of metaknowing can be either epistemic or pragmatic (for a distinction between epistemic and pragmatic actions, see Kirsch & Maglio, 1994). Regarding the quality of arguments per se, as defined here as epistemic, the following assessment criteria have been proposed in the field of informal logic (Johnson & Blair, 1994): (a) relevance, indicating either the relevance of the premises offered in a single argument or the relevance of a proposition to an issue under discussion; (b) sufficiency, indicating whether the premises provide sufficient evidence for the conclusion to be drawn, and (c) acceptability, indicating that the premises of an argument should be acceptable to the arguer, the audience to which the argument is directed, and, in general, to the critical community in which they are situated. However, the quality of argumentation can also be judged in terms of the fulfillment of an action, defined here as pragmatic and thereby indicating the achievement of an evident relevant goal resulting from the argumentative activity. The various assessment constructs described should facilitate the decision regarding what the instruction should focus on to promote argumentation and critical thinking.
Teaching/learning argumentation and critical thinking

The terms “critical thinking” and “higher order thinking” have been frequently used interchangeably in the literature. Some have defined these terms as goal-directed, reflective, and reasonable thinking when evaluating the evidence for an argument for which all the relevant information may not be available (Cotton, 1997; Crowl et al., 1997; Facione, 2000; Lewis & Smith, 1993; Patrick, 1986); as an essential component in the metacognitive processes (Crowl et al., 1997); as analysis, inference, interpretation, explanation, and self-regulation; or as requiring inquisitive, systematic, analytical, judicious, truth-seeking, open-minded, and confident dispositions toward critical-thinking processes (Facione, 2000). Halpern (1998) defines critical thinking as the deliberate use of skills and strategies that increase the probability of a desirable outcome (p. 1), while Van Gelder (2005) defines it as thinking that helps one determine whether to believe some claim, and if so, how strongly to believe it. As he posits:

Van Gelder (2005) proposes, in a paper titled “Lessons from cognitive science”, seven tips for teaching critical thinking skills. His lessons integrate well the approach taken in this chapter. The seven tips are summarised as follows. (1) Critical thinking skills are difficult to acquire because their acquisition requires a deliberate effort to learn through practise [skillfully exercising (p. 6)]. For instance, Zohar (2004) developed a project for teacher professional development. She explains how the teachers participating in the project were not aware that they were engaged in teaching critical thinking. In other words, their teaching of critical thinking skills was an intuitive part of their teaching methodology. Accordingly, teaching for thinking played no conscious role in their planning, and thus, they never engaged in metacognitive activities with their students. (2) Because practise leads to improvement, teachers should provide opportunities for students to continuously practise critical thinking skills. (3) Opportunities for transfer should be provided by practising not only the skills but also the transfer of those skills into other domains and contexts. (4) Teachers should provide practical theory by explicitly examining the theoretical aspects of critical thinking. For instance, teachers can explicitly teach the difference between “evidential reasons (reasons providing evidence that a claim is true) and explanatory reasons (reasons which assume the claim is true and go on to explain how and why the situation came about)” (p. 13). Again, one of Zohar’s conclusions supports this premise. She found that teachers were quite proficient in solving problems that required the application of critical thinking skills, but they were often unable to verbalise the thinking patterns they had used during their efficient conclusion. Nonetheless, the teachers were able to explicitly teach critical thinking skills. (5) Teachers should help students overcome the human bias toward belief confirmation by encouraging students to actively explore the evidence against their beliefs, thereby being able to anticipate and respond to counter arguments. (6) Teachers should teach students to regularly map the argument chain in a diagram that shows the logical structure and sequence of one’s argument. Finally, Van Gelder proposes the promoting of intrinsic motivation to think critically. Accordingly, he argues that the teacher should not use rewards and should avoid extrinsic motivation. Rather, he encourages teachers to set up critical thinking activities through which students learn to enjoy critical thinking.
Cognitive analysis of learning argumentation

Over the past few decades, the constructivism perspective has dominated the teaching-learning practices in science education. The main underlying assumption was that teachers must be aware of students’ prior knowledge. Beyond this need, new movements are emphasising the need for science teachers to understand how students reason and the need for these teachers to develop the ability to address the various reasoning modes of students (Duschl & Grandy, 2008). This requires specific knowledge of students’ thinking strategies and their reasoning difficulties when creating professional development courses that target these specific needs. As mentioned by several authors (Driver et al., 2000; Zeidler, 1997), teachers’ lack of pedagogical strategies to support students as they engage in reasoning, as well as the limited resources available to assist teachers as they attempt to support students, could explain the lack of emphasis on argumentation in school science. However as Zeidler contends, “It is unrealistic to expect teachers to adopt argumentation as a pedagogical practice to teach science if they do not themselves develop more elaborated understandings of argumentation in the context of science learning” (1997, p. 485).

There is wide consensus that the primary function of reasoning is argumentation (Kuhn, 1992; Mercier & Sperber, 2011). On the one hand, reasoning is updated through argumentation processes, while, on the other hand, argumentation benefits from sound reasoning. For an analysis of the processes involved in argumentation, we depart from Moshman’s distinction between “inference”, “thinking”, and “reasoning”. Moshman defines inference as the generation of new cognitions from old cognitions. Children tend to make inferences from an early age, though normally in an unconscious manner. Thinking is defined as the deliberate coordination of one’s inferences to serve one’s purposes, for instance, when one justifies a claim or tests a hypothesis. Finally, Moshman (1998) makes the claim that when thinking is evaluated with respect to how well it serves the purposes of the thinker, it corresponds to reasoning. According to the degree of consciousness involved, thinking is considered an advanced form of inference, and reasoning is an advanced form of thinking. For our psychological analysis, we make the claim that “thinking” in Moshman’s sense is the point of departure of an argument, whereas “reasoning” would be the point of departure for sound argumentation. Thinking implies the coordination among theory, evidence and methodologies (Garcia-Mila & Andersen, 2008; Moshman, 1998), while reasoning involves, in addition to the former, the dialectical process of coordinating multiple claims in a framework of evaluating multiple alternatives and evidence (Kuhn, 1991), with both of them requiring reflection. In cognitive terms, to go from thinking to reasoning, there is a progressive need of metacognition. At the lowest end of the reflection spectrum, we find reasoning, which simply justifies a claim (i.e. the early arguments made by young children who effectively defend their position in a quarrel), and at the highest end, we find sophisticated arguments made by expert arguers where alternatives to one’s own claims are considered, evaluated and counter argued. Thus, sophisticated argumentation requires the arguer to consider both sides of an issue and to be open to new evidence that may disconfirm one’s belief. The former begins with the ability to separate theory from evidence, progressing towards bracketing one’s own theory by taking the perspective of the potential opponent and overcoming the difficulties associated with generating alternative theories and counterarguments.

Research in science education has shown that there is a great gap between thinking and reasoning among individuals. Studies show that justifying claims is relatively easy from an early age, but when asked to participate in debates with several alternative positions, individuals of all ages show certain weaknesses (Garcia-Mila & Andersen, 2009). More concretely, students have difficulty engaging with another’s statements, making claims that do not address the opponent’s claims and thereby do not undermine their partner’s position (Pontecorvo & Girardet, 1993).
In other cases, they tend to make claims that are unrelated to the rest of the elements in the argument (Felton, Garcia-Mila, & Gilabert, 2009; Jiménez-Aleixandre, et al., 2000). When individuals are asked to explicitly clarify their disagreement or position, they make simple claims without taking into consideration alternative views that could potentially generate counterarguments or rebuttals, thus interrupting the depth of the sequence.

In their developmental study comparing adolescents and adults, Felton and Kuhn (2001) found that both age groups justify their claims clearly but that younger students tend to make a significantly higher number of clarifications of their own claims compared to the number of times they ask for clarification of their partner’s position or critique their partner’s position. Furthermore, the authors show that although adolescents may demonstrate some use of counterargument, their discourse goal seems to be to improve one’s own position rather than to undermine their partner’s argument. Kuhn (1999) explains these weaknesses in terms of the developmental differences in metaknowing that enable adults to engage in more effective argumentative discourse, with the underlying competence of these skills being metacognition. In contrast to first-order cognitive skills that enable one to know about the world, metacognitive skills are second-order metaknowing skills that entail knowing about one’s own (and others’) knowing (p. 17). “Skills are only one part of a more complex structure that develops, with second-order metaknowing components both arising from and feeding back to support the use of first-order cognitive skills” (Kuhn, 1999, p. 24).

Do these developmental differences between adolescents and adults apply to differences between students and science teachers? As Newton et al. (1999) argued, little is known about how science teachers (pre-service and in-service) engage in scientific argumentation. Zembal-Saul, Munford, Crawford, Friedrichsen, and Land (2002), confirming the above-mentioned reasoning trends, found that it was easy for pre-service science teachers to link claims to evidence by conducting an analysis of the quality of the evidence. However, their arguments did not include an analysis of alternative explanations. Pre-service teachers tended to align with one of the two alternatives provided without considering the other to be a viable option. The former would be thinking of one’s own thoughts (to know about the world) as a sign of first-order thinking, while the latter would require one to engage in thinking (to know about one’s own (and others) knowing), which involves second-order metaknowing skills with metacognition as the key to higher order thinking (Kuhn, 1999, p. 17).

Learning to teach argumentation: professional development of teachers

There is limited research on teachers’ learning and professional development in argumentation (e.g. Simon & Johnson, 2008; Simon, et al., 2006; Zembal-Saul, 2009; Zohar, 2007). Anat Zohar, who has contributed extensively to research in science teaching and teacher education states that “until very recently, very little work has been done specifically about teacher education and professional development in the field of argumentation” (Zohar, 2007, p. 246). Plethora of research studies have focused on the teaching of higher order thinking skills (e.g. Zembal-Saul, 2009), a related skills set that facilitates the processes of argumentation as discussed earlier. However, the incorporation of the ‘epistemic’ components of argumentation in teaching is still quite challenging for science teachers. Teachers not only need to coordinate the cognitive but also the epistemic goals of science education in developing scientific inquiry. Teachers need to learn about effective pedagogical strategies that would enable students to carry out activities that would rely on the used of evidence-based reasoning, critical thinking and argumentation (Erduran, Ardac, & Yakmaci-Guzel, 2006; Zembal-Saul, 2009; Zohar, 2007).
Learning to teach argumentation is a goal not only for in-service but also pre-service teachers (e.g. Erduran, 2006; Kell et al., 1998; Kim & Song, 2006; Richmond & Striley, 1996; Zembal-Saul et al., 2002). The models of professional development of in-service teachers include the training of pre-service trainee teachers (e.g. Simon & Maloney, 2006; Erduran, 2006) typically involving both higher education-based training and school-based practical experience. The provision for professional development of in-service teachers tends to be sporadic with limited opportunities for long-term learning experiences. In England and Wales, for instance, the Science Learning Centres have been instrumental in the delivery of professional development on the argumentation-related components of the curriculum in a systematic way (Erduran & Jimenez-Aleixandre, 2012).

For argumentation to take place in science classrooms, teachers need to facilitate that students assume an active role in discussions (Jimenez-Aleixandre & Erduran, 2007). Yet, as Newton (1999) indicated, science lessons tend to be conducted with a heavy emphasis on question and answer interactions, and the teacher-dominant practices in science lessons do not tend to involve activities that support discussion, argumentation or the social construction of knowledge. Therefore, a significant issue about teaching argumentation is the need for teachers to coordinate and mediate related epistemic practices of science in the learning environment so as to allow student participation in discussions (Duschl, 2008; Simon, Erduran, & Osborne, 2006).

Integrating argumentation research with professional development research is essential to understand what is needed for enhancing teachers’ skills in promoting and supporting argumentation in the science classroom. In particular, teachers’ knowledge of teaching is critical for effective coordination and teaching of higher order thinking skills. Cochran-Smith and Lytle (1999) offer three ways to conceptualise teachers’ knowledge and practice:

Knowledge-for-practice – This view of teacher learning assumes a “distinctive knowledge base” for teaching that exists primarily within the university teacher education community and is delivered to prospective teachers during their teacher education programmes. Teachers, whether pre-service or in-service, are consumers – not producers – of knowledge.

Knowledge-in-practice – This view of teacher learning assumes that much of the expertise for teaching lies within the artistry occurring in the moment-to-moment life of classrooms. Artisan teachers – those who have mastered the craft of teaching – have developed a portfolio of knowledge about classroom practice. Teacher learning hinges on reflection and analysis of one’s teaching practices to develop deeper awareness of decision making underlying the craft of teaching.

Knowledge-of-practice – This view of teacher learning assumes that the knowledge needed for teaching is co-constructed by groups of teachers as they systematically conduct inquiries into issues of teaching and learning, issues of subject matter and curriculum, and issues of schools and society. Teachers’ practice extends beyond the practices occurring within their classrooms and includes the practice of collaborative inquiry for professional growth.

Given the complexity of skills required of teaching, all forms of knowledge are likely to be required for learning to teach argumentation as well. Teachers are also role models in communicating to students how they envisage knowledge and knowledge growth. Through their pedagogical conduct and practices teachers implicitly model knowledge and ways of knowing (e.g. Conley et al., 2004; Hofer, 2001; National Research Council [NRC], 1996, 2000). In other words, teachers are instrumental in getting students to think critically about what counts as knowledge and how knowledge is constructed, developed, evaluated and revised.
Simon, Erduran, and Osborne (2006) identified a range of strategies that science teachers who are effective in promoting argumentation exhibit in their lessons. These authors state that “to help teachers progress in their teaching of argumentation, our data would suggest that the focus of professional development should be on teachers’ existing understanding of the importance of evidence and argument in science and on their implicit goals of teaching and learning science. To this end, the research has helped to identify a tentative hierarchy of student argumentation processes, reflected within teachers’ argumentation goals” (p. 256) which is illustrated in Table 32.1. The implementation of the pedagogical strategies would enable students to learn to listen, talk, justify claims and engage in higher order skills such as counter-arguing and reflection.

Few studies have been conducted to trace the development of science teachers in learning to teach argumentation in a longitudinal fashion. Erduran and Dagher (2007) studied the development of two middle-school science teachers who participated, over five years, in various school-based research projects on argumentation ranging from basic research in teaching and learning to the development of professional development programmes for training teachers in argumentation. The projects took place between 1999 and 2004 in the United Kingdom funded by the Economic and Social Research Council (Osborne, Erduran, & Simon, 2004a), Nuffield Foundation (Osborne, Erduran, & Simon, 2004b) and the Gatsby Foundation (http://www.cpdthroughpoe.com/index.html). The teachers were asked to reflect as a pair on various

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<tr>
<th>Codes for teacher utterances that reflect goals for argumentation</th>
<th>Categories of argumentation processes as reflected in teacher utterances</th>
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<tbody>
<tr>
<td>Encourages discussion</td>
<td>Talking and listening</td>
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<tr>
<td>Encourages listening</td>
<td>Knowing meaning of argument</td>
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<tr>
<td>Defines argument</td>
<td>Positioning</td>
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<td>Exemplifies argument</td>
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<td>Encourages ideas</td>
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<td>Encourages positioning</td>
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<td>Values different positions</td>
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<td>Checks evidence</td>
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<td>Provides evidence</td>
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<td>Prompts justification</td>
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<td>Emphasises justification</td>
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<td>Encourages further justification</td>
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<td>Plays devil’s advocate</td>
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<tr>
<td>Uses writing frame or written work/prepares presentations/gives roles</td>
<td>Constructing arguments</td>
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<td>Encourages evaluation</td>
<td>Evaluating arguments</td>
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<td>Evaluates arguments</td>
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<td>Process – using evidence</td>
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<td>Content – nature of evidence</td>
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<tr>
<td>Encourages anticipating counter-argument</td>
<td>Counter-arguing/debating</td>
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<tr>
<td>Encourages debate (through role play)</td>
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<tr>
<td>Encourages reflection</td>
<td>Reflecting on argument process</td>
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<tr>
<td>Asks about mind-change</td>
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Source: Simon, Erduran, and Osborne, 2006.
aspects of teaching and learning of argumentation. The results address the teachers’ views and knowledge of argumentation, their perceptions of the goals, constraints and successes in their teaching of argumentation, their perceptions of themselves as learners and teachers, and their reflections on the professional development that they received.

Reflections of both teachers displayed sophisticated understanding of argument as well as its teaching and learning. Their recommendations centred around effective professional development to take into account a holistic presentation of teaching scenarios and a range of student abilities. Both teachers indicated that their own success with the project was due to their persistence in learning something new and the nature of the workshops conducted with them and other teachers – which have been published subsequently (Osborne, et al., 2004a, 2004b). They also indicated that among many teaching strategies, they are now more conscious of doing group work and they view the ability to conduct and coordinate group discussions as a significant skill that can be transferred to other aspects of teaching. When asked to reflect on what kinds of developmental and cognitive skills they would expect students to undergo in the learning of argumentation, both teachers referred to a scheme used in the research project to analyse the quality of student argumentation in group discussions. The scheme derived from a theoretical account of argument based on Toulmin’s work (1958) focussed on the use of rebuttals and the use of data and warrants to support one’s claim while another person is in opposition to an original claim (Erduran, Simon, & Osborne, 2004). Both teachers, whose classroom practices included meta-level language with students about the nature of rebuttals (Simon, Erduran, & Osborne, 2006), indicated that a development in argumentation skills would necessitate the presence of improved skills with rebutting an argument.

Teachers’ professional development in argumentation has been reviewed by Erduran and Jimenez (2012). For instance, the work of argumentation in professional development in the Mind the Gap Project (Erduran & Yan, 2010, 2009) has been extended in the context of the S-TEAM Project (Science Teaching Advanced Methods) funded by the European Union FP7 Programme. One of the strands of this project provided resources and strategies to help teachers to create learning environments for argumentation and the learning of discursive practices in science (Jiménez-Aleixandre, Puig, & Gallástegui, 2010). A key priority of the S-TEAM Project was to disseminate training resources and classroom materials to support the teaching and learning of argumentation in science classrooms and the development of teachers’ reasoning about the nature of scientific knowledge.

Despite some success stories, research evidence also suggests that the teaching of and professional development in argumentation can pose numerous challenges. Curricular goals can hinder the effective implementation of teaching and teacher training if they are not in line with the learning outcomes intended by innovative pedagogical approaches such as argumentation (Erduran, 2006). A further component of complexity in the implementation of effective professional development programmes can be the diversity of interpretations of the national curricula. For example in England and Wales context, the exam boards such as EdExcel and OCR interpret the National Curriculum policy level statements for the design and implementation of teaching. Different exam boards tend to have different interpretations of the “How Science Works” (HSW) agenda, the component of the science curriculum that included themes such as argumentation (Lavelle & Erduran, 2007).

**Merging epistemic, cognitive and pedagogical accounts of argumentation**

As our review illustrates, argumentation is a significant context for teachers to mediate students’ understanding of how scientific knowledge is constructed. It is also a territory where cognitive and
epistemic dimensions of science and of learning can be coherently integrated. It is widely known that teachers influence how students acquire new knowledge by choosing particular pedagogical practices (e.g. Shulman, 1986). Given teachers’ choices of pedagogical practices may lead to differences in student achievement (e.g. Hofer, 2001), choices of pedagogical practices related to argumentation may result in students’ acquisition of skills to justify scientific knowledge claims.

Whilst policy and research recommendations unite in promoting argumentation in science classrooms, significant gaps remain between educational policy, research, and practice in the context of inquiry teaching and in argumentation in particular. Provision for professional development in argumentation is still quite rare (Zohar, 2007). One approach that has aimed to transform research and policy findings for professional development purposes is the project called “Mind the Gap: Learning, Teaching and Research in Inquiry-Based Science Teaching” funded by the European Union (Erduran & Yan, 2010). In infusing ideas about argumentation into professional development of science teachers, an evidence-based approach was used to apply some of the key outcomes of research on teacher education. For example, the work of Supovitz and Turner (2000) guided the model of professional development where it was deemed important to engage participants in inquiry, questioning and experimentation in a collaborative manner. Furthermore, the project relied on the principles of teachers’ collaborative exchanges with peers and reflective inquiries into their own teaching.

Inherent in our review is the concern not about what students know, but about how they come to know what they know. For students to acquire knowledge, it is imperative that they develop in their ways of knowing. How teachers facilitate students’ acquisition of ways of knowing as well as the associated cognitive skills are questions that underpin research on argumentation in science education. Teachers will be able to help students understand the criteria, standards and heuristics that enable argumentation to take place if they themselves can be engaged in the cognitive and epistemic practices of science to develop their own thinking skills, argumentation abilities and pedagogical strategies.

References

Epistemic practices and thinking in science


