Chapter 1
Argumentation in Science Education: An Overview

María Pilar Jiménez-Aleixandre and Sibel Erduran

Charles Darwin once described *On the Origin of Species* as “one long argument”. This sentence can be viewed as embodying several of the different dimensions of argumentation discussed in this book. On the one hand, it provides evidence, coming from someone with undisputable authority, on argument being an integral part of the construction of scientific knowledge. On the other hand, when applied to the outstanding piece of scientific thinking that is *On the Origin of Species*, the description combines two aspects of argumentation. The first aspect relates to the justification of knowledge claims, by marshalling converging lines of reasoning (see Kelly, Regev, & Prothero, this book), theoretical ideas and empirical evidence toward a claim. Darwin weaved together population theory from Malthus, or uniformitarianism from Lyell, with empirical data gathered in his voyage to Central and South America in his bold claim of the theory of natural selection. A second aspect of argumentation has to do with argumentation as persuasion, in Darwin’s case as an attempt to convince an audience, composed both of scientists and of the general public, that the animals and plants had changed, that the species living on Earth descended from other species instead of having being created all at a time. Darwin was well aware that the task of persuading his contemporaries was not an easy one, such awareness being one of the reasons for delaying the publication of his book for about twenty years. In fact a joint presentation by Darwin and Wallace in the Linnean Society in 1858 stirred little interest, and the president of the Society summarised the year as one that “has not indeed been marked by any of those striking discoveries which at once revolutionize science” (Beddall, 1968, pp 304–305). However, one year later, the publication of Darwin’s book launched a great controversy, corresponding yet to another aspect of argumentation, as debate among two parties with contrasting positions on a subject.

Argumentation, in whatever sense it is conveyed, is an integral part of science and we argue it should be integrated into science education. In this chapter, we present an overview of a line of research in science education whose main purpose has been exactly such attempts to make argumentation a component of instruction and learning. Indeed the field on argumentation in science education has been receiving growing attention in recent years. Firstly we outline a rationale for why should we, teachers or science educators, promote argumentation in science classrooms. Second we discuss different meanings of argumentation and some

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approaches to its study, particularly those relevant for science education. In the third section we turn our attention to an overview of some themes from international policies for science curricula that provide a context and a rationale for the inclusion of argumentation in science education worldwide. We conclude the chapter with a brief link to some of the earlier work that formed the foundation of argumentation studies in science education. Overall, our discussion illustrates the theoretical, empirical and policy level conceptualisations in the study of argumentation in science education which point to the significance of research in this area.

Why Argumentation in the Science Classroom?

In recent years, a growing number of studies are focusing on the analysis of argumentation discourse in science learning contexts (e.g., Driver et al., 2000; Jiménez-Aleixandre et al., 2000; Kelly & Takao, 2002; Zohar & Nemet, 2002). These works draw, among others, from two related frameworks. One framework is related to science studies highlighting the importance of discourse in the construction of scientific knowledge (Knorr-Cetina, 1999; Latour & Woolgar, 1986) and consequences for education (Boulter & Gilbert, 1995; Erduran et al., 2004; Pontecorvo, 1987). A second framework is the sociocultural perspective (Vygotsky, 1978; Wertsch, 1991) which points to the role of social interaction in learning and thinking processes, and purports that higher thinking processes originate from socially mediated activities, particularly through the mediation of language. To these could be added an interest in democratic participation, which requires debate among different views rather than acceptation of authority. The implication is that argumentation is a form of discourse that needs to be appropriated by students and explicitly taught through suitable instruction, task structuring and modelling.

From these approaches a view can be derived about science learning in terms of the appropriation of community practices that promote the modes of communication required to sustain scientific discourse (Kelly & Chen, 1999; Lemke, 1990; Mason, 1996). Such a view stands in contrast to the traditional views of science learning that focus only on outcomes such as problem-solving, concept learning or science-process skills. Science learning is thus considered to involve the construction and use of tools that, like argumentation, are instrumental in the generation of knowledge about the natural world (Kitcher, 1988). Argumentation plays a central role in the building of explanations, models and theories (Siegel, 1995) as scientists use arguments to relate the evidence they select to the claims they reach through use of warrants and backings (Toulmin, 1958). The case made is that argumentation is a critically important discourse process in science, and that it should be promoted in the science classroom (Duschl & Osborne, 2002; Jiménez-Aleixandre et al., 2000; Kelly et al., 1998; Zohar & Nemet, 2002). A significant question, however, is why argumentation deserves to be promoted in the context of science learning. Put more specifically, what is the rationale for introducing argumentation in science learning?

Andrée Tiberghien (this book) frames this question in the theory of “didactic transposition” (from the French *transposition didactique*, where *didactic* does not have the standard English meaning of traditional approach, but the less charged significance of the original Greek “related to teaching”, common to most Indo-European languages). Tiberghien discusses the external referents for the legitimisation of argumentation, distinguishing two aspects: one it’s about the place of argumentation in science education and the other about the connections between argumentation and citizenship education. She summarises the place of argumentation in science education in terms of three goals: knowledge about nature of science; developing citizenship and developing higher order thinking skills. With an approach complementary to Tiberghien’s exploration of external referents, in this section we elaborate on the rationale for argumentation appealed to from within the educational community, and particularly the science education community.

We propose that there are at least five intertwined dimensions or potential contributions from the introduction of argumentation in the science classrooms:

- Supporting the access to the cognitive and metacognitive processes characterising expert performance and enabling modelling for students. This dimension draws from the situated cognition perspective and the consideration of classrooms as communities of learners (Brown & Campione, 1990; Collins et al., 1989).
- Supporting the development of communicative competences and particularly critical thinking. This dimension draws from the theory of communicative action and the sociocultural perspective (Habermas, 1981; Wertsch, 1991).
- Supporting the achievement of scientific literacy and empowering of students to talk and to write the languages of science. This dimension draws from language studies and social semiotics (Kress et al., 2001; Norris & Phillips, 2003; Yore et al., 2003).
- Supporting the enculturation into the practices of the scientific culture and the development of epistemic criteria for knowledge evaluation. This dimension draws from science studies, particularly from the epistemology of science (Leach et al., 2003; Sandoval, 2005).
- Supporting the development of reasoning, particularly the choice of theories or positions based on rational criteria. This dimension draws from philosophy of science (Giere, 1988; Siegel, 1989, 1995, 2006) as well as from developmental psychology (Kuhn, 1991, 1993).

These contributions influence one another, although they are discussed separately, for the clarity of discussion. It has to be noted that by qualifying these contributions as potential we imply that their achievement is not necessarily warranted by the introduction of argumentation in the classroom. We acknowledge that the execution of these dimensions in the science classroom require a coordinated, complex and systematic set of pedagogical, curricular and assessment initiatives, among others. Table 1.1 summarises the dimensions and the perspectives or bodies of knowledge framing the dimensions.

Table 1.1 Contributions of argumentation and perspectives framing contributions

Potential contributions of argumentation	Drawing from
Making public and modelling cognitive processes	Situated cognition; communities of learners
Developing communicative competences, critical thinking	Theory of communicative action; sociocultural perspective
Achieving scientific literacy; talking and writing science	Language studies; social semiotics
Enculturation into scientific culture; developing epistemic criteria	Science studies; epistemology
Developing reasoning and rational criteria	Philosophy and developmental psychology

When pointing out the different fields or perspectives from which science education draws in promoting argumentation in the classroom, the implication is not that this is a one-way relationship. We believe that science education itself, through studies on argumentation, holds the potential to inform these perspectives in their disciplinary settings as well, leading to truly interdisciplinary investigations of argumentation. In other words, we contend that reciprocal contributions between these "feeding fields" and science education are desirable and fruitful in the production of knowledge in the field of argumentation studies.

Making Cognitive Processes Public: Argumentation and Situated Cognition

Constructivist perspectives view learning as a process of knowledge construction. A seminal piece of work supporting this claim was produced by Collins et al. (1989) who proposed to organise teaching as cognitive apprenticeship where knowledge and skills learning are integrated in their social and functional contexts. This proposal is related to Lave and Wenger's (1991) notion of situated learning, conceiving learning as increasing participation in a community of practice. Cognitive apprenticeship seeks to relate these knowledge and skills to their use in the real world. As Collins and colleagues point out, current pedagogical practices make invisible the key aspects of expertise, paying little or no attention to the processes through which experts acquire or use knowledge while performing complex or real tasks, for instance higher order processes. Applying the notion of apprenticeship to skills that are cognitive in nature requires internalisation of external processes. However in current educational contexts neither the teacher nor the students have access to the cognitive processes of each other, thus rendering impossible the observation or modelling of these processes. It may be noted that cognitive processes are made public through language and that natural language is both a tool and an obstacle for building scientific knowledge.

Brown and Palincsar (1989) base their proposal of guided cooperative learning in Vygotsky's (1978) notion of the social genesis of individual comprehension and in Toulmin's (1958) argumentation structure. These authors point to the role of collaboration in providing models of cognitive processes, as the thinking strategies are performed in public, modelling what then has to be performed privately. Argumentation in the context of classrooms where students are participants in a community of learners (Brown & Campione, 1990; Mason, 1996) may thus support the development of higher order cognitive processes (one of the goals for science education mentioned by Tiberghien, this book), given that reasoning becomes public and students are expected to explicitly back their statements with evidence and to evaluate alternative options or explanations.

Developing Communicative Competencies and Critical Thinking

Both critical theory and sociocultural perspectives view educational and mental processes in connection with their social and historical contexts. The critical theory conceived in the Frankfurt School can be described as a reflection on the relationships among social goals, means and values. For critical theory the goal of technical progress cannot be placed higher than democracy, and education is assigned a central role in social transformation. Carr and Kemmis (1986) contrast critical rationality and technical rationality, the latter being a perspective that views all problems as technical issues, depriving people from the capacity of controlling the world around them, with the consequence of diminishing the capacities of reflection and modification of situations by means of action.

For Jürgen Habermas (1981) critical theory is a form of self-reflective knowledge that expands the scope of autonomy, thus reducing domination. In his theory of communicative action Habermas distinguishes four types of social actions: (a) teleological, or goal oriented; (b) norms regulated (c) dramaturgical, or a performance in front of an audience constituted by the participants in the interaction; and (d) communicative, oriented to understanding one another in order to coordinate planned actions. Language and communicative competencies play a central role in communicative action: people reflect about themselves and about the world, and share these explanations with others. The theory of communicative action gives people pre-eminence over structures, assigning them the potentiality to develop actions directed to social change. As Kelly (2005) notes, in Habermas' framework, individual shifts to a social epistemic subject whilst reason is centred on communicative action and norms for argument are shared.

The perspectives of critical theorists contribute to a view of classrooms as places for communication. The acknowledgement of the importance of communication, of the relevance of language in knowledge construction, pointed out by Vygotsky (1978), is contributing to new lines of work in science education about the role of language in science learning, for instance in meaning making (Mortimer & Scott, 2003).

Given the theoretical precedence of the role of communication in education, it is essential to pay a closer look at the development of students' communicative competencies.

The need for promoting critical thinking has been advocated from different philosophical and psychological positions. From a philosophical perspective, Ennis (1992) defines critical thinking as reasonable reflective thinking focused on deciding what to believe in or do, and provides a set of criteria for assessing it. For Siegel (1992) a critical thinker refers to an educational ideal, and he emphasises the rationale for the assessment component of critical thinking and the disposition of critical thinkers to seek evidence for their beliefs. Understood as the search for evidence, critical thinking would be closely related to developing rational criteria, a position also maintained by some cognitive psychologists like Kuhn who explains the development of scientific reasoning as the coordination of theory and evidence (Kuhn, 1991; Garcia-Mila & Andersen, this book). But although critical thinking from the perspective of critical theory entails contrasting theories and beliefs with evidence, it also has a component related to the issue of emancipation. Furthermore critical thinking from this perspective is related to developing the capacity to criticise discourses which contribute to the reproduction of asymmetrical relations of power (Fairclough, 1995), or as Paulo Freire (1970) put it, to empowering students to understand the society around them and their own capacity to transform it. Teachers creating environments where students engage in argumentation about socio-scientific issues (see for instance Simonneaux, this book) include, among their goals, the development of critical thinking. Such critical thinking is related to the development of citizenship (Tiberghien, this book), of educating citizens that are critical thinkers, in the sense not only of a commitment to evidence, but also of an empowerment for critical rationality, the capacity to reflect on and influence social issues of relevance for their lives. Critical thinking can further be framed relative to scientific scepticism, as a tool for confronting pseudoscience and credulity.

Achieving Scientific Literacy: Talking and Writing Science

The recent focus on the role of spoken and written language in science learning seeks to redress an overemphasis on the recipe-like empirical (laboratory experiences) and rote mathematical (formulae) components of scientific knowledge in the classroom. Such change of focus cannot be seen as a return to rote-memory learning or use of textbooks as sole resources, in so far as it is rooted in a notion of the interpretative use of language and in the recognition of the importance of meaning construction (Mortimer & Scott, 2003). Norris and Phillips (2003) advocate the centrality of reading (interpreted as inferring meaning from text) and writing in learning science. In a similar vein, Yore et al. (2003) demand attention to the literacy component of science literacy, such as, for instance, critical reading of different sources, or participation in debates and argumentation among other modes of communication and communicative resources in the science classroom (Kress et al., 2001).

Lemke (1990) drew attention to the centrality of talk in science learning and to the need of promoting students' true dialogue or "talking science", a way of learning the language of science. Lemke's approach, grounded in the work of Mikhail Bakhtin (1986) who conceived communication as a social phenomenon, considers both scientific talking and scientific writing as social practices. The focus on discourse means an exploration of the features of texts that have rhetorical significance (Myers, 1990). Texts can be viewed as part of the social processes involved in the production of scientific knowledge, of the negotiations of the place and value of a claim in the structure of scientific knowledge given that science writing cannot be seen as reporting, but as construction of scientific facts (Myers, 1990). By engaging in argumentation students learn to talk and write the languages of science (see for instance Kelly et al., this book; Mason, 1998), including the rhetorical features (Kelly & Bazerman, 2003; Martins et al., 2001) such as persuasion in argumentation.

Enculturation in the Practices of Scientific Culture: Developing Epistemic Criteria

Learning science involves epistemic apprenticeship, the appropriation of practices associated with producing, communicating and evaluating knowledge (Kelly & Duschl, 2002). Kelly (2005) defines epistemic practices as the specific ways members of a community propose, justify, evaluate and legitimise knowledge claims within a disciplinary framework. With a focus on the science classroom, epistemic practices are defined by Sandoval and Reiser (2004) as the cognitive and discursive practices involved in making and evaluating knowledge, practices related to students' development of epistemological understanding. This epistemological understanding is viewed by Garcia-Mila and Andersen (this book) as cognitive foundation for argumentation. Leach and colleagues (2003) proposed teaching interventions aimed to foster epistemic understanding. Their studies are set in the context of an agenda exploring epistemic goals and practices, of a shift of focus on processes rather than on end products of science learning.

The appropriation by students of practices of the scientific community or the enculturation in the scientific culture is related to students' understanding of scientific epistemology—what in the literature is known as *personal* epistemologies. Kelly (2005) points to the social nature of the science epistemology, as epistemic criteria for justifying and evaluating knowledge are developed as social norms in a given community. Fostering students' appropriation of the epistemic practices of the scientific community is related to the goal of developing students' knowledge and skills about the nature of science proposed by Tiberghien (this book). Sandoval (2005) distinguishes among students' formal and practical epistemologies, the former being beliefs about professional science, the latter about their own practices with inquiry. Sandoval highlights an important reason for promoting the development of sophisticated epistemologies: the effective participation in policy decisions and the interpretation of scientific claims relevant for their lives, claiming that such outcomes are crucial for democracy. We see this dimension of epistemic understanding associated with the meaning of critical thinking discussed earlier. Argumentation, with its emphasis on justification of claims and on the coordination among claims and evidence, may support the development of epistemic criteria and more generally the enculturation in the practices of the scientific community. The relationships among argumentation and epistemology are discussed in detail in Sandoval and Millwood, and the development of epistemic criteria in Duschl (both chapters in this book).

Developing Reasoning and Rational Criteria

In a way, it could be argued that the development of the capacity of choosing among theories or positions is part of the development of epistemic criteria discussed in the previous section. For some authors, as already mentioned, rationality and critical thinking are treated as being almost synonymous. However, the ongoing controversy in science education as well as in philosophy of science (sometimes referred to as "science wars") locates rationality, epistemology and radical constructivism, among other issues as pivotal in relation to science learning. The "science wars" debate, as Peters (2006) puts it in his editorial for the special issue on philosophy of science education in *Educational Philosophy and Theory*, has been silenced in many occasions or publicised by means of a biased account, as in the Sokal affair. Incidentally, it may be noted that as the Hwang case sadly proves, scientific journals (*Science*, no less), and not only social studies journals, can be successfully hoodwinked into publishing forgery. Although these debates exceed the scope of this chapter, we consider the concept of rationality relevant for our purposes particularly in relation to science education and argumentation.

First, it has to be noted that issues surrounding rationality are complex issues, where different perspectives can be seen in a continuum, rather than in extreme black or white irreconcilable sides. We (the authors of this chapter) contemplate science both as a rational enterprise *and* as a social construction. There is no denying that scientific research is influenced by ideology, power or commercial interests. For instance, the issue of gender is tightly related to critiques of science, particularly given that perspectives of women and other marginalised sectors are conventionally underrepresented. But, as the feminist Sandra Harding (1991) argues, recognising sociological or cultural relativism does not entail epistemological relativism but rather a search for the most objective knowledge claims. In other words "A feminist standpoint epistemology requires strengthened standards of objectivity" (p. 142) leading to less distorted beliefs in natural phenomena.

If we agree that science is, or ideally should be, a rational enterprise then how can we define its rationality? For Siegel (1989, 2006) literature fails to distinguish three different questions about rationality. According to Siegel the central question is: What counts as evidence for some scientific hypothesis or procedure? In other words, Siegel sees rationality of science as being grounded in a commitment to evidence. On the other hand Siegel conceives of critical thinking as the educational cognate of rationality, involving consistency, impartiality and fairness. Siegel's perspective on rationality has not gone unnoticed nor uncriticised. For instance, Finocchiaro (2005) criticises Siegel's identification of critical thinking as rationality, proposing instead the notion of reasoning aimed at interpretation, evaluation or self-reflective presentation of arguments (critical reasoning) or methodological reflection. As discussed above, our own perspective is grounded on rationality as commitment to evidence whilst at the same time-sharing some of the tenets of the critical theory. In particular, we contend that critical theories enrich Siegel or Finocchiaro definitions by including the reflection about social environment and the potential to transform society. In terms of a philosophical referent, the resulting perspective could be rooted in the idea about the unfinished project of modernity (Habermas, 1997, 1981). For Habermas the modernity project, formulated by the Enlightenment, is based on rationality and its lack of vigour means, not that the Enlightenment goals should be discarded, but that they have not be achieved.

In summary, it can be said that the epistemic criteria developed to choose among theories or positions are rational criteria and their development may be supported by argumentation. In Fig. 1.1 we summarise some potential contributions of argumentation to the goals of science education implied by our discussion so far.

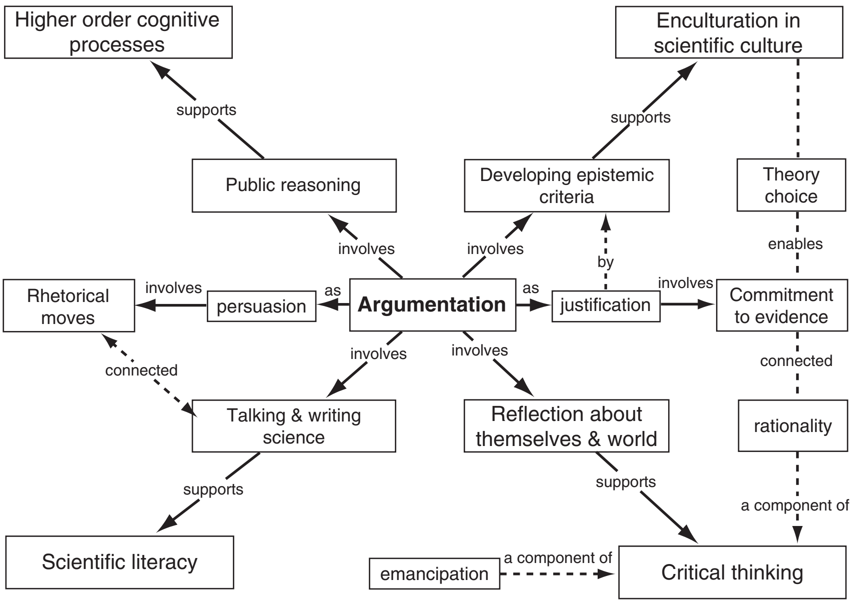

Fig. 1.1 Potential contributions from argumentation

Science education is conventionally seen as addressing goals of two sorts, which can be summarised as “science for all” and “science for prospective scientists”. Our position is that argumentation can contribute to both goals. More particular goals of contributing to the development of higher order cognitive processes, enculturation into scientific practices and epistemological understanding are also represented in the figure.

From the discussion so far some may be tempted to conclude that argumentation is a solution to most science education problems. This is not an implication that we wish to project. Rather we conceive of argumentation, on the one hand as a solution for some learning problems, to the extent that it helps students learn things that are hard to learn except through argumentation (e.g., evaluating evidence) and on the other hand as holding the potential to help us better understand and support the learning processes in the science classroom.

Meanings of Argument

For the purposes of this book it is important to clarify what we mean by argument. Is argument a statement or a process? Does an argument need to be produced by an individual or can it be co-constructed across individuals? Is argument always related to a dialogical context or can it take place internally in individuals’ minds? With respect to the last question, we agree with Billig (1987) who, in discussing the Greek philosopher Protagoras’ position on argument, points out that *argument* has both an individual and a social meaning: “The individual meaning refers to any piece of reasoned discourse. As one articulates a point of view, one can be said to be developing an argument” (p. 44). The social meaning is that of a dispute or debate between people opposing each other with contrasting sides to an issue. In other words, an argument can be either an inner chain of reasoning or a difference of positions between people and, as Kuhn (1993) notes, there is a link between the two. Social argumentation is a powerful vehicle for developing the higher order thinking that we call internal argumentation. In other words, social dialogue offers a way to externalise internal thinking strategies embedded in argumentation.

Not all authors would agree with this double meaning as, for instance, van Eemeren and Grootendorst (2004) restrict the meaning of an argument to the social one: “Argumentation is a verbal, social and rational activity aimed at convincing a reasonable critic of the acceptability of a standpoint by putting forward a constellation of propositions justifying or refuting the proposition expressed in the standpoint” (van Eemeren & Grootendorst, 2004, p. 1). For Plantin (personal communication) this definition, while apparently emphasising social aspects, adopts an entirely individual perspective. Perhaps both positions can be partly reconciled if, as Kuhn and Udell (2003) propose, we use the terms *argument* for the product, statement or piece of reasoned discourse and *argumentation* or argumentative discourse for the social process or activity, discussed in more detail in Garcia-Mila and Andersen (in this book). About the individual versus co-constructed production, we consider that both cases are possible, as illustrated in some empirical studies in other chapters.

From the different meanings of argumentation, at least two that are combined in van Eemeren and Grootendorst definition, are relevant for the science classroom context: argumentation as knowledge justification and argumentation as persuasion. We see this distinction related to two types of text construction discussed by Myers (1990, p. 103): scientific arguments, referenced in evidence, and narratives that function by persuasion. In science, knowledge construction is linked to knowledge justification, and claims should be related either to a path of logical clauses or to data and evidence from different sources (or to both). Hence, argumentation in scientific topics can be defined as the connection between claims and data through justifications or the evaluation of knowledge claims in light of evidence, either empirical or theoretical. Scientific claims are thus differentiated from opinions. Driver et al. (2000), Duschl and Osborne (2002) and Kuhn (1992), among others, suggest that science education should promote argumentation as one of the dimensions of learning science, and of the enculturation in the scientific discourse. Garcia-Mila and Andersen (this book) claim a broader relevance for argumentation, viewing it as a process aimed at the rational resolution of questions and involved in general knowledge acquisition. Other authors from philosophy have defined argumentation mainly in reference to justification. For instance according to Finocchiaro (2005) an argument is “an instance of reasoning that attempts to justify a conclusion by supporting it with reasons or defending it from objections” (p. 15).

Argumentation as persuasion can be defined as the process of convincing an audience (van Eemeren & Grootendorst, 2004). Acknowledgement of the role of discursive practices in the construction of scientific knowledge suggests that discourse has to be considered as being relevant for the appropriation of scientific culture by students. For Driver et al. (2000) the interpretation of argumentation as discursive practice is involved in the process of reaching agreement on acceptable claims or courses of action. Acknowledging the role of discourse does not mean that it is not possible to develop criteria for evaluating knowledge claims. We agree with Siegel (1989) and Driver et al. (2000) that argumentation is a rational process that relies on the rigorous application of knowledge evaluation criteria.

Our review of the meaning of argumentation will benefit from an historical overview of argumentation studies, as for instance, presented by Plantin (1996, 2005). For Plantin a turning point in these studies was the publication in 1958, of seminal work by Toulmin (1958) as well as Perelman and Olbrechts-Tyteca. On the focus on argumentation by these books, Plantin concurs, was a move towards legitimisation of a field discredited because of its association with rhetoric. Plantin sees the discredit of rhetoric in France at the end of the nineteenth century as being related to the prevalence of positivist views. The historical method was considered to yield legitimate knowledge whereas rhetoric, conceived as persuasion and even associated with trickery with words, was deemed not scientific, leading to the disappearance of the teaching of rhetoric from the French universities. After the Second World War, the ideological context changed. The emergence of argumentation studies can be interpreted as a reflection of the increasing attention at rationality of discourse as well as an attempt to promote "the construction of a democratic rational discourse, rejecting totalitarian Nazi or Stalinist discourses" (Plantin, 2005, p. 15; our translation). The life story of Chaïm Perelman (a scholar of Jewish origin) who contributed to the defence of Belgian Jews during the war, lends further support to the influence of the post-war context for the importance of rhetoric and rationality.

Perelman and Olbrechts-Tyteca (1958) subtitle their book as "the new rhetoric," and define argumentation theory as the study of discursive techniques that allow for the trigger or increase of adherences to proposed theses. The rationale they construct has the purpose of achieving value judgements, and consists of discursive techniques or tools that enable the justification of decisions or choices. Perelman and Olbrechts-Tyteca distinguish persuasive from convincing argumentation, the former being addressed to a particular audience whereas the latter addresses any rational being and is universal in nature. It has to be noted that there is a long tradition of argumentation and rhetoric studies in French exemplified by the seventeenth-century work *Logic or the Art of Thinking* (Arnauld & Nicole, 1992), also known as the *Port-Royal Logic*, work that Finnocchiaro (2005) regards as a precursor of argumentation and informal logic studies. Arnauld and Nicole treatise deals with issues such as the relationship between truth and intelligibility, or the principles of reasoning relevant to the discovery and justification of contingent truths. More recently, in the last decades of the twentieth century, several interesting studies on argumentation were produced in France derived from the field of language sciences. For instance, Anscombre and Ducrot (1983) emphasise the role of language in argumentation whilst Grize (1982) focuses on cognitive processes, providing a framework that is used by several French science education researchers (Buty & Plantin, in press). Unfortunately, there is paucity of English translations of the seminal historical texts as well as of the educational research in argumentation. One example of argumentation analysis using Grize's ideas is the work of Simonneaux (this book).

The argumentation model or scheme of Stephen Toulmin (1958) can be seen as a move towards the study of argumentation as it is practised in the natural languages, and therefore away from the schemes of formal logic. Insofar as the relationships between formal logic and logic in the natural discourse are concerned, we agree with Hintikka (1999) that formal logic remains inadequate for inferences leading to new discoveries: "the truths of formal logic are mere tautologies or analytical truths without substantial content and hence incapable of sustaining any inferences leading to new and even surprising discoveries" (p. 25). For Díaz and Jiménez-Aleixandre (2000) the implication is that while it could be used to represent or analyse *established knowledge*, formal logic is not an adequate framework to interpret discourse in situations where *new knowledge* is being generated. In situations consisting of natural discourse, for instance when solving a problem in the science classroom or laboratory, many propositions could be not correct or even fallacious from the perspective of formal logic, while at the same time constituting fruitful steps in the construction of knowledge. Toulmin himself sought to describe argumentation in practice and thereby challenge the notion of deductive validity.

He made a distinction between idealised notions of arguments as employed in mathematics and the practice of arguments in linguistic contexts, which, for him, should have close ties with epistemology. Toulmin was committed to a procedural interpretation of argumentation form as opposed to the rigid idea that all arguments have the form of "premises to conclusions". Any justification of a statement or set of statements is, for Toulmin, an argument to support a stated claim. In other words, he places the validity of an argument in the coherence of its justification. In Toulmin's model of argument, sometimes referred to as Toulmin's Argument Pattern or TAP, an argument needs to make appeals to data, warrants, backings and qualifiers. Such appeals are context dependent. (For applications of Toulmin's work in the analysis of classroom data on argumentation, see Erduran in this book).

Examining the form of arguments from different fields (e.g., law, science and politics), Toulmin was able to discern that some elements of arguments are the same while others differ across fields of inquiry. Toulmin termed the elements of arguments that are similar across fields as being field-invariant features of arguments whereas those elements that differed were called field-dependent features. Data, claims, warrants, backings, rebuttals and qualifiers are field-invariant, while "what counts" as data, warrant or backing are field-dependent. Thus, appeals to justify claims used to craft historical explanations would not necessarily be the same kind of appeals used to support claims for causal or statistical-probabilistic explanations. The flexibility of Toulmin's model to function in both field-dependent and field-invariant contexts provides an advantage for understanding and evaluating the arguments posed by students in science.

Toulmin's work has received much criticism. Plantin (2005), for instance, argues that Toulmin's scheme is a model of rationale discourse adequate primarily for a monologue, although he appreciates the inclusion of the modal qualifier that can be conceived as the introduction of an element of dialogue. In science education some authors (e.g., Duschl, this book) have pointed to the inadequacies of TAP to account for dialogic argumentation, proposing instead the use of other models such as Walton's (1996) as being more appropriate for the study of classroom discourse.

Walton (1996) frames his dialectical approach to argumentation in informal logic. For Walton (1989) in order to analyse argumentative discourse on controversial issues in natural language a number of questions must be taken into account, as for instance careful attention to language or the ability to deal with vagueness and ambiguity, and the researcher must be prepared to unravel the main line of argument from long exchanges among two or more people. Walton points out that in this dialectical approach the question–answer context of an argument is brought forward and an argument is seen as a part of an interactive dialogue of two (or sometimes more) people reasoning together. Walton's (1996) argumentation schemes for presumptive reasoning are grounded on presumption as a practical notion that is used to enable a dialogue or an action to go ahead on a provisional basis. So it may be that not all the evidence that would be needed to reach a definite claim or option (or course of action) is available. Walton also offers an interesting distinction about explicit and implicit commitments of participants in a dialogue. He sees the commitment set of each participant as divided in two sides:

> a *light side*, a set of propositions known, or in view, to all the participants, and a *dark side*, a set of propositions not known to, or visible to, some or all of the participants. This dark side represents the implicit commitments. (Walton's emphasis, Walton, 1996, p. 26)

This distinction has been used by Jiménez-Aleixandre, Agraso and Eirexas (2004) in their analysis of students' arguments about an oil spill. Walton's typology of argumentation schemes can be interpreted also as a typology of justifications or warrants, or as a typology of appeals.

International Policies, Science Curricula and Argumentation

Apart from academic rationales for the promotion of argumentation in science education, there are policy level indications that argumentation as a skill is important worldwide. Computing technologies and trends in globalisation have contributed to a renewed vision that citizens across the world need to deal with a vast set of information and be able to evaluate such information. A significant aspect of such skills is the ability to argue with evidence. Internationally the phrasing of the national science curricula has begun to incorporate more of an emphasis on the need to teach students the skills of interpreting, evaluating and debating information. In addition, international comparative studies such as the Third International Mathematics and Science Study (TIMSS) have offered a rationale and support for reform needed in many countries. Likewise, the Programme for International Student Assessment (PISA) has been a driving force in the advancement of skills such as the ability to coordinate evidence and claims. PISA is an internationally standardised assessment that was jointly developed by participating countries and administered to 15-year-olds in schools. The survey was implemented in 43 countries in the first assessment in 2000, in 41 countries in the second assessment in 2003, in 57 countries in the third assessment in 2006 and 62 countries have signed up to participate in the fourth assessment in 2009. Tests are typically administered to between 4,500 and 10,000 students in each country.

The PISA Assessment Framework, although does not mention argumentation as a term, explicitly emphasises the role of evidence in the reaching of conclusions:

> An important life skill for young people is the capacity to draw appropriate and guarded conclusions from evidence and information given to them, to criticize claims made by others on the basis of the evidence put forward, and to distinguish opinion from evidence-based statements. Science has a particular part to play here since it is concerned with rationality in testing ideas and theories against evidence from the world around. (OECD, 2003, p. 132)

Furthermore, there is emphasis on the role of knowing and applying of processes to select and evaluate information and data (p. 133). Indeed the very definition of scientific literacy is framed in terms of evidence-based conclusions (p. 137).

Scientific literacy is envisaged as involving three main processes: (a) describing, explaining and predicting scientific phenomena; (b) understanding scientific investigation; (c) interpreting scientific evidence and conclusions. An example assessment framework incorporating the third strand is given in Appendix A.

Across the world, there is an increasing trend to incorporate ideas about how scientific knowledge construction occurs and how argument can contribute to the process of scientific knowledge construction. In the United States, American Association for the Advancement of Science (AAAS) and the National Research Council (NRC) have been strong advocates and supporters of reform (AAAS, 1993; NRC, 1996). For example, the "Science as Inquiry Standard" emphasises the importance of students' understanding of *how* we know what we know in science. In the United Kingdom, the importance of argument, the justification of claims with evidence, is recognised as an educational goal through the *Ideas and Evidence* (DfES/QCA, 2004) and *How Science Works* (QCA, 2007) components of the National Science Curriculum. The basic position underlying these components of the curriculum is that students should leave schooling with a deeper sense of the nature of scientific knowledge—how ideas are produced, evaluated and revised in science. In upper secondary schooling at Key Stage 4, the Qualifications and Curriculum Authority states that:

> "How science works" focuses on the evidence to support or refute these ideas and theories. The evidence comes from the collection and creative interpretation of data, both of which need to be considered. Consequently, in order to understand how science works, learners need skills such as practical collection of data, working safely, presenting scientific information; they need to understand the power of science to explain phenomena, the way understanding of science changes over time and the applications of contemporary scientific developments. (QCA, 2007)

In the new Spanish National Curriculum for secondary schooling the relevance of the use of evidence and of argumentation is emphasised both in the general definition of basic competencies and in the description of goals in the science subjects. For instance the basic "Competency about knowledge and interaction with the physical world" states that:

> This competency ... enables to engage in rational argumentation about the consequences of one or another way of life, and to adopt a stance towards a healthy life both physically and mentally (...) This competency makes possible to identify questions or problems and to draw conclusions based on evidence, with the goal of understanding and making decisions about the physical world and about the changes produced by human activity in the environment, the health and people's quality of life. (MEC, 2007, p. 687; our translation)

The description of the contributions of science to the basic competencies also highlights "a particular way of constructing discourse, aimed at argumentation" (MEC, 2007, p. 692) and includes the skill of argumentation among the general objectives of science education for compulsory secondary school, from 12 to 16 years.

In the secondary science curriculum in South Africa, one of the learning outcomes focuses on the nature of science and its relationships to technology, society and environment. Here the expectation is that:

> The learner is able to identify and critically evaluate scientific knowledge claims and the impact of this knowledge on the quality of socio-economic, environmental and human development. It is important for learners to understand the scientific enterprise and, in particular, how scientific knowledge develops. (Department of Education, 2003, p. 14)

Furthermore, the South African science curriculum acknowledges a philosophy of science that places the tentative nature of science at the forefront of instruction, highlighting the value of evidence in the building of scientific knowledge:

> Scientific knowledge is tentative and subject to change as new evidence becomes available and new problems are addressed. The study of historical, environmental and cultural perspectives on science highlights how it changes over time, depending not only on experience but also on social, religious and political factors. (Department of Education, 2003, p. 11)

In Turkey, the national reform efforts have promoted informed citizenship where individuals make evidence-based judgements in their everyday lives including issues that relate to science. Some of the middle-school curricular goals specify in particular the role of argumentation as well as students' role in the construction of scientifically valid points of view:

- To encourage students' argumentation and evaluation of alternative ideas
- To mediate debates and activities in a way so as to allow for the possibility of students' own constructions of scientifically accepted views and mindsets …
- To encourage students' skills in generating hypotheses and alternative interpretations in explaining phenomena (MEB, 2005, p. 15, our translation)

The work on argumentation directly relates to the following two standards in the Turkish National Curriculum which lists one of the aims of science education as helping students (a) gain skills in research, reading and debate whereby learners are involved in new knowledge construction; and (b) understand the nature of science and technology as well as the relationship between science, technology, society and environment.

In Israel, the Harari report (Tomorrow 98, 1992) by the committee appointed by the Ministry of Education to examine the state of science, mathematics and technology instruction, under the leadership of Harari, cites that greater comprehension of the importance of science and technology knowledge helps pupils make decisions regarding national and international issues. Science and technology teaching is aimed at recognising the possibilities and limitations of both disciplines when applying them to problem-solving. These courses develop smart consumer thinking and behaviour by using a decision-making process when selecting a product or a system.

In Australia, the Curriculum Council of Western Australia (1998) recommends that:

> Typically, students learn to plan investigations using scientific knowledge to select or adapt equipment where necessary. They should learn to appreciate the value of doing exploratory work to refine the investigation process and use appropriate ways to record and display their data, draw their conclusions and interpret them in the light of current scientific knowledge. Students need time at the end of investigations to allow for the recognition of

> confirming and refuting evidence and sources of possible errors, as well as to attempting to correct them. (p. 235)

Even though this document does not explicitly state the use of argument in science education, the language involving the use of data drawing conclusions from data as well as the recognition of confirming and refuting evidence implicitly points to the features of argument and argumentation.

In numerous science-education policies across the world, the trends highlight the significance of making science relevant to students' lives through links to technology, society and environment. Taiwan has developed new *Science and Life Technology Curriculum Standards* (SaLTS) for Grades 1–9 (Chang, 2005). SaLTS feature a systematic way for developing students' understanding and appreciation of individual–society–nature interactions. The role of evidence typically tends to play out in these arguments in informed citizenship although there is also indication that the role of evidence, debate and argument in scientific knowledge growth is also acknowledged. Often however the link to argumentation is not explicit except for some policy documents such as the National Education Standards (Curriculum Guidelines) for Grade 1–9 in Science and Technology Discipline in Taiwan:

> Students will gain related knowledge and skills through learning science and scientific inquiry; meanwhile, they will think scientifically and use what they have learned to solve problems for them having been used to *do discussions and argumentation* according to scientific methods. Students will therefore *realize the nature of knowledge and form a habit of valuing evidence and reasoning* through scientific inquiry frequently. When facing and dealing with problems, students will try to understand them and solve them with a positive attitude of curiosity and exploration. We call it "scientific and technological literacy" including all the knowledge, viewpoints, abilities, attitudes and applications discussed above. The main goal of learning in science and technology discipline is to foster our citizens' scientific and technological literacy. (translated document)

In other cases such as the Chilean National Science Curriculum, the notions of argumentation and justification are contextualised in particular examples embedded in problem-solving tasks such as the one reproduced in Appendix B (MEC, 2004, p. 41). The National Curriculum for General Science in Pakistan (NCGS, 2006) promotes an inquiry-based curriculum where there is an emphasis on skills such as the ability to provide evidence for conclusions:

> Inquiry requires students to describe objects and events, ask questions and devise answers, collect and interpret data and test the reliability of the knowledge they've generated. They also identify assumptions, provide evidence for conclusions and justify their work. (p. 59)

As the preceding overview of the worldwide reform efforts in science-education policy illustrates, there is an increasing emphasis on resting the science curriculum on a more appropriate balance between science process and citizenship skills, and factual or content knowledge of science. The main rationale for the inclusion of argumentation in the science curriculum has been twofold. First, there is the need to educate for informed citizenship where science is related to its social, economic, cultural and political roots. Second, the reliance of science on evidence has been problematised and linked in the context of scientific processes such as investigations, inquiries and practical work. The advance of such efforts is a signal that the science teaching needs to change to match the needs of citizens as well as scientists. The inclusion of the assessment of argumentation in the PISA framework is an encouraging signal that acknowledges the significance of argumentation as an important skill. Likewise the presence of worked out examples of argument-based tasks in National Curricula such as the Chilean Science Curriculum would provide an impetus to the adoption of argumentation at the level of the classroom.

Despite such efforts at the level of international policies about the science curriculum, the systemic uptake of argumentation work in everyday science classrooms remains minimal. One of the key challenges to implementing argumentation in everyday classrooms is the lack of transformation of policy recommendations to educational practice. The gap between research, policy and practice, a familiar problem in educational research (e.g., Hargreaves, 1996) is perpetuated by the fact that few research projects have extended the findings to a larger scale of teaching and learning scenarios, for instance through translation of their research to professional development of new teachers. The Nuffield-funded IDEAS project aimed to bridge this gap where school-based research into teaching and learning of argumentation has been applied to the design of a professional development programme involving exemplars video clips of argumentation teaching and learning, and resources for supporting pupils' argumentation in the science classroom (Osborne et al., 2004).

The production of research-based professional development programs, on the other hand, have highlighted the importance of giving both in-service and pre-service science teachers the opportunities to engage in tasks that are meaningful in their teaching contexts (e.g., Simon et al., 2006; Taber, 2006). The Key Stage Three Strategy of the Department for Employment and Skills (DfES) in the United Kingdom supported a network of projects to enable "ideas and evidence" to be a component of initial teacher training (e.g., Erduran, 2006). By inviting university-based researchers to participate in a policy-driven initiative to support initial teachers' training in this area, the DfES extended the national policy on "Ideas and Evidence" to the research arena. The outcome of the project included a resource pack for Initial Teacher Training (ITT) providers subsequently funded by the Gatsby Charitable Foundation. These resources have been adapted for ITT in other national contexts (e.g., Turkey) in an effort to make argumentation a component of pre-service teacher education (Erduran et al., 2006).

From Early Argumentation Studies to Future Directions

The policy level rationales for the inclusion of argumentation in science education have accompanied, if not somewhat in a delayed fashion, the theoretical and empirical justifications for why argumentation is needed in science education.

Most international policies began to emphasise the role of evidence and justifications in scientific inquiry since late 1990s. The first studies about argumentation in science classrooms explored, since at least the 1980s, knowledge construction along with the social dimensions of argumentation such as the role of authority and leadership in group dynamics. For instance, Russell (1983) used Toulmin's (1958) scheme to analyse teachers' questions in terms of their role in the development of arguments framed either in rational (evidence) or traditional (status) authority concluding that traditional authority was prevalent. Eichinger et al. (1991), in their study about 6th graders discussing which water state is appropriate to transport water in a space ship, combined argument analysis with the exploration of social interactions. These researchers suggested that the students reached a consensus about adequate claim and justification, not because of a deep understanding, but because one of the leaders decided to support the only student who offered an adequate justification.

The role of ethnicity, though an understudied research area in relation to argumentation, has received some attention contributing to the cultural studies of argumentation. Stephen Druker (2000) analysed the influence of practices and resources originated out of school in the argumentation strategies of Indonesian students belonging to two ethnic groups, finding higher frequency of agreement in the Javanese, related to a culture which places great value in social harmony. Jiménez-Aleixandre et al. (2000) explored the influence of the school culture in the production of arguments by secondary school students. Cultural and sociological studies of argumentation promise an exciting new research domain where issues such as power and gender can be investigated and conceptualised for argumentation in science classrooms. Another potential direction of future research is interdisciplinarity where argumentation is studied from a wider range of theoretical and empirical perspectives. An example would be collaborations among researchers in linguistics, philosophy and science education so as to inform how argumentation can be better situated in schooling.

We began our chapter with a reference to Darwin's "long argument". Perhaps it is appropriate to end it by expressing the hope that argumentation will be commonplace in science classrooms. The teaching of evolution remains under challenge 150 years after the publication of *On the Origin of Species*. Argumentation will empower students for distinguishing claims made on scientific grounds from those based solely on tradition and authority.

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Appendix A

Example from PISA Assessment Framework on Interpreting Scientific Evidence and Conclusions (OECD, 2003, p. 144).

Science Example 2.2

Suppose that on one stretch of narrow road Peter finds that after the lane lines are painted the traffic changes as below.

Speed	Traffic moves more quickly
Position	Traffic keeps nearer edges of road
Distance apart	No change

On the basis of these results it was decided that lane lines should be painted on all narrow roads. Do you think this was the best decision? Give your reasons for agreeing or disagreeing.

Agree: _____

Disagree: _____

Reason: ____________________

Scoring and comments on Science Example 2.2

Full Credit

Code 1: Answers that agree or disagree with the decision for reasons that are consistent with the given information. For example:

- Agree because there is less chance of collisions if the traffic is keeping near the edges of the road, even if it is moving faster
- Agree because if traffic is moving faster, there is less incentive to overtake
- Disagree because if the traffic is moving faster and keeping the same distance apart, this may mean that the drivers do not have enough room to stop in an emergency.

No Credit

Code 0:	Answers that agree or disagree without specifying the reasons, or provide reasons unrelated to the problem.
Item type:	Open-constructed response
Process:	Interpreting scientific evidence and conclusions (Process 3)
Concept:	Forces and movement
Situation:	Science in technology

Appendix B

Argumentation embedded in problem-solving task (MEC, 2004, p.41).

Unit 2: Change and conservation in phenomena involving chemical reactions
They boil an egg in water for about 5 to 6 minute, let it cool and cut it carefully. They analyse the changes that happened and *discuss*:

- If they could get back the hard boiled egg to its initial condition by cooling it
- If the change occurred inside the egg is reversible or irreversible
- If the phenomenon of decoction is physical or chemical
- What properties of the egg have changed? (mainly aspect, consistency, colour of white and yolk and taste)
- Whether they can *justify their arguments* to affirm or deny that the egg suffered a change of state and became solid
- What properties of the egg did not change? (shape, colour and aspect of the shell)
- If the eggshell experienced a chemical or physical change and how can they justify their answer