# Chapter 45
# Revisiting School Scientific Argumentation from the Perspective of the History and Philosophy of Science

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## 45.1 Argumentation in Science and in Science Education

The purpose of this chapter is to examine the notion of scientific argumentation as it is applied in the realm of science education nowadays, but this examination is done – in accordance with the thematic thread of this handbook – shifting from the extensively used discursive perspective to one centred on *metatheoretical* issues. In order to set an initial consensus for the discussion that follows, it might be convenient to advance here a broad definition of argumentation, which will be eventually revisited to incorporate more theoretical elements. Using the phrasing on the back cover of Myint Swe Khine's (2012, n/p) compilation, scientific argumentation could be loosely identified with 'arriving at conclusions on a topic through a process of logical reasoning that includes debate and persuasion'. This definition points out that an argument typically involves (a) supporting an assertion on other elements, (b) a range of options when choosing such elements and (c) strategies to convince the argument's recipients that the favoured option is appropriate.

Literature reviews around argumentative practices in the science classroom rapidly conduct to acknowledging that argumentation is a central issue or focus – or more properly a 'line of research' (Jiménez-Aleixandre and Erduran 2008) or a 'strand' (Nielsen 2011) – within current didactics of science (i.e. science education as an academic discipline). However, such reviews show, at the same time, that 'argumentation in the field of science education has constituted itself into a multi-disciplinary topic, most profoundly approached from language sciences' (Archila 2012, p. 363;

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my translation). Hence, the interest of this chapter to recover an *epistemic* focus, which could be broadly defined, borrowing Greg Kelly and Charles Bazerman's words, as the recognition

> that writing and argument play important roles in scientists' and technologists' thinking and forming knowledge communities […]. The forms of expression, invention, and knowledge are responsive to the particular argumentative fields of the professions and disciplines. The epistemic activity of researchers is shaped by rhetorical concerns of who is to be convinced of what, how others respond to novel work, what the organization of their communicative activity is, and what the goals of community cooperation are […]. The representation and role of evidence in relation to generalizations and claims has been a particularly crucial matter in the development of scientific argument. (Kelly and Bazerman 2003, pp. 28–29)

Indeed, argumentation has been recognised by some traditions, authors and texts in the philosophy of science as a key epistemic feature of the scientific enterprise,[1] i.e. a feature constitutive of its very nature, which serves to *demarcate* science from other human activities. It could arguably be stated that

> the majority of philosophical conceptions on the structure of a scientific theory, as well as some of the most important models of [scientific] explanation, incorporate argumentation (understood as justifying inferences) as a central piece in the scientific machinery. (Asti Vera and Ambrosini 2010, p. 6; my translation)

This argumentation-based perspective on the nature of science is apparent in Stephen Toulmin's (1958) famous book, *The uses of argument*, especially in essay IV, where he examines 'substantial arguments' in the experimental sciences. But it should be noted that although argumentation-like processes have been consistently considered in the metatheoretical discussion of scientific processes and products by philosophers (e.g. Giere et al. 2005), the use of the expression 'scientific argumentation' is not as extended as it could be expected within the philosophy of science – at least until very recently. This may be partly due to the concealment of the more elaborate communicative aspects of science in the rather formalist, syntactic view 'received' from the Vienna Circle. In the philosophy of science, the idea of scientific argumentation has been very usually rephrased in terms of explanation, justification, debate, controversy, judgement, persuasion, rhetoric, etc.

Many portrayals of science-in-the-making have pointed to the existence of an extremely elaborate, social, use of *evidences* to give support to our complex, articulated understandings of the natural world (i.e. *scientific explanations*) and, at the same time, to *convince* other people that such understandings are plausible

[1] See the following 'focussed' philosophy of science textbooks for more or less extensive discussions around philosophers that inspect the centrality of argumentation in science: Asti Vera and Ambrosini (2010), Føllesdal and Walløe (1986), and Salmon (1995). Also of particular interest for this chapter are the portrayals of the 'combined' scientific practice of argumentation-explanation that revolve around the notion of *abductive* reasoning (cf., Adúriz-Bravo 2005; Aliseda 2006; Bex and Walton 2012; Giere 1988; Giere et al. 2005; Lawson 2009; Samaja 1999).

and fruitful.[2] Such accounts of the nature of science share four main characteristics:

1. They consider explanation – in argumentative contexts – as one of the core epistemic practices of science (cf., Bricker and Bell 2008; Jiménez-Aleixandre and Erduran 2008; Khine 2012, who all cite the *philosophical* origins of this idea that has been imported into didactics of science).
2. They revolve around the notion of evidence (or data, proof, reasons, supporting assertions, warrant and a host of other phrasings) as a key to understand scientific semiosis (i.e. meaning production).
3. They highlight the constituent intentions of the 'acts of speech' (*à la* John Searle) or 'language games' (*à la* Ludwig Wittgenstein)[3] included in the very fabric of the scientific activity (cf., Asti Vera and Ambrosini 2010).
4. They acknowledge the social and situated character of the aforementioned processes, which are developed at the interior of specific knowledge communities with their rules and values.

In accordance with this pre-eminent role given to argumentation in science, it has been repeatedly suggested from didactics of science that argumentation should be incorporated as a major component in a high-quality science education for all (cf., Erduran and Jiménez-Aleixandre 2008; Jiménez-Aleixandre 2010; Osborne 2005). The consideration of argumentation as a central process of 'scientists' science' has permitted didacticians of science (i.e. science educators as researchers) to advance at least three main reasons for the inclusion of argumentation in 'school science'[4] (cf., von Aufschnaiter et al. 2008, p. 102):

1. Meaningful and critical science learning requires argumentation. In this sense, 'learning to argue is seen as a core process […] in learning to think and to construct new understandings [, since] comprehending why ideas are wrong matters as much as understanding why other ideas might be right' (Osborne 2010, p. 464). Thus, mastering the argumentative aspects of science and examining actual pieces of scientific argumentation would help distinguish claims and statements that are supported from those that are not, and also to assess the

[2] Leema Kuhn Berland and Brian Reiser (2009) also present a three-element characterisation of argumentation, which is very similar to the one proposed here. They talk about: '(1) using evidence and general science concepts to *make sense of the specific phenomena being studied*; (2) *articulating these understandings*; and (3) *persuading others of these explanations* by using the ideas of science to explicitly connect the evidence to the knowledge claims' (p. 29; emphasis in the original).

[3] These two theoretical constructs refer to the communicative activity as a whole, with all its pragmatic constraints, where different types of texts – among them, arguments – are produced.

[4] The distinction here between 'scientists' science' and 'school science' (cf., Izquierdo-Aymerich and Adúriz-Bravo 2003) is based on the French tradition in *didactique des sciences*. In the theory of didactical transposition (Chevallard 1991), there is a 'savoir savant' constructed within the disciplines and a 'savoir enseigné', taught at school, which emerges from transposing (i.e. performing adaptive operations on) the former. Thus, science as done at school resembles in some aspects, and differs in some others from, science as performed by scientists.

quality and pertinence of the supports provided. It could be safely stated that this first reason is very general, goes beyond scientific argumentation and its epistemology and values arguing in all its cognitive, metacognitive and communicative dimensions,[5] linked to 'fostering the development of students' rationality' (Siegel 1995, p. 159).

2. Since scientists produce and evaluate arguments all the time in order to do science, a school science that is structured around argumentation would convey important messages about the nature of science, hence the need to inform argumentation-based instruction with findings from the philosophy and history of science. In coherence with this second reason, in science classes, a non-negligible part of students' activity would be to construct arguments around their understandings of the natural world, and to share, defend and criticise such arguments as it is done in actual scientific practice (cf., Driver et al. 2000, for school science, and Giere 1988, for scientists' science). Here we could use the distinction proposed by Marilar Jiménez-Aleixandre and colleagues (2000) between doing authentic school science and 'doing the lesson', the first one being characterised by 'the generation and justification of knowledge claims, beliefs, and actions taken to understand nature' (p. 758). It should be noted, of course, that the resulting nature of science that would circulate in the classroom *would heavily depend on the notion of argumentation that is being implemented*, be it more 'rationalist' or more 'constructivist' (see the 'tensions' defined in Sect. 45.2).
3. When considering science education as a tool for scientific literacy and citizen education, it is suggested that students need to engage in argumentation in order to tackle decision-making and to participate in socioscientific debates similar to those that they will encounter in their adult lives. As Jiménez-Aleixandre and colleagues (2000) point out: one of the most currently valued educational goals is 'equip[ping] students with capacities for reasoning about problems and issues, be they practical, pragmatic, moral and/or theoretical' (p. 757); it has been repeatedly proposed that argumentation would foster such capacities. Those capacities would involve evaluating different pieces of scientific evidence and judging their relative importance in making decisions around key issues of personal and social importance. Along this line, and closely following the French linguist Christian Plantin (2005, 2011), Pablo Archila states that

> argumentation has been positioning itself as a social imperative, if it is considered as a way to treat differences, eliminating them, or moving them forward towards collective welfare […]; [education for citizenship] can resort to argumentation to justify, on the basis of shared values, the existence of positions on debated issues that are socially sensitive, such as racism, abortion, the defence of the environment, war, women and children, animal rights, among others. (Archila 2012, p. 364; my translation)

Thus, there is strong consensus that 'student participation in argument develops communication skills, metacognitive awareness, critical thinking [reason 1 above],

[5] An anonymous reviewer of this chapter suggested the inclusion of this remark. Emphasis on this central 'learning to learn' aspect of argumentation is probably a cause for the blurring of its more specific epistemic aspects, linked to the nature of science.

an understanding of the culture and practice of science [reason 2], and scientific literacy [reason 3]' (Cavagnetto 2010, p. 336).

Due to this interest in the diverse contributions of argumentation to science education, in the last decade a vast and rapidly expanding corpus of literature has accumulated in didactics of science.[6] Several possible approaches to the study of argumentation in school science have been put forward, related to the theoretical conceptualisations utilised and to the practical aims sought.[7] In this sense, '[a]ccording to different conceptualizations in this domain [of argumentation studies] instructional accounts to promote argumentative abilities of students also differ considerably' (Böttcher and Meisert 2011, p. 104). It could be added that, in consistency with those different conceptualisations, the 'natures' of science propounded for instruction also differ.

Underneath the variety of approaches, different intellectual threads can be recognised. A number of disciplines, fields of study or theoretical frameworks have converged to help didacticians of science in the task of defining, fostering and assessing argumentation in science education.[8] Nevertheless, the epistemic perspective, where an HPS[9] background would be of use, has been somewhat obscured by active discussion from linguistic, cognitive, ethnographic or pedagogical perspectives. Indeed, as stated above, most research around the place of argumentation in science education has been developed within the area of 'research with a focus on classroom discourse during the teaching and learning of science' (von Aufschnaiter et al. 2008, p. 103), with some studies also focussing on written argumentative products (cf., Adúriz-Bravo et al. 2005; Bell and Linn 2000; Erduran et al. 2004). Thus, the interest has been mainly put in the strictly *linguistic* aspects.

[6] In Archila (2012), Buty and Plantin (2008a), Erduran and Jiménez-Aleixandre (2008), Jiménez-Aleixandre (2010), Jiménez-Aleixandre and Díaz de Bustamante (2003), Khine (2012), Nielsen (2011), Sampson and Clark (2006, 2008), and Sanmartí (2003), there are rather comprehensive literature reviews on the subject, with more than three hundred references in English, French and Spanish.

[7] For example: Abell and colleagues (2000), Adúriz-Bravo and colleagues (2005), Bell and Linn (2000), Driver and colleagues (2000), Duschl (1990), Duschl and Osborne (2002), Fagúndez Zambrano and Castells Llavanera (2009), García Romano and Valeiras (2010), Henao and Stipcich (2008), Islas and colleagues (2009), Konstantinidou and colleagues (2010), Lawson (2003), Linhares Queiroz and Passos Sá (2009), Newton and colleagues (1999), Osborne and colleagues (2001), Revel Chion and colleagues (2005), Ruiz and colleagues (2011), Sanmartí (2003), Sasseron and Carvalho (2011), and Schwarz and colleagues (2003).

[8] See, for instance, Cadermártori and Parra (2000), Candela (1999), Kuhn (1992), Martins (2009), Mason and Scirica (2006), and Pontecorvo and Girardet (1993), among a host of others, for theoretical foundations ranging from psychologist James F. Voss to semiotician Mikhail Bakhtin, going through argumentation theorist Frans van Eemeren and social anthropologist Jean Lave.

[9] I will here use the acronym HPS (history and philosophy of science in/for science education) to denote the area of research within didactics of science that strives to incorporate a metatheoretical perspective in science education (cf., Matthews 1994/2014, 2000). This area would mainly draw from the meta-sciences (philosophy, history and sociology of science), but it would also include elements from the science studies and from other 'less disciplined' metatheoretical endeavours, such as science-technology-society (STS), feminist epistemologies or public understanding of science.

In order to transcend this discursive approach, and to recover substantive links between scientific argumentation and metatheoretical reflection on the nature of science, the aim of this chapter is threefold:

1. Identifying and characterising a subset of literature on argumentation in science education where connections to HPS are apparent or can be unproblematically proposed.
2. Spotting there some of the 'bridges' that are explicitly announced or can be implicitly recognised between mainstream HPS and argumentation in the science classroom, such as evidence-based science education, inquiry, nature of science and scientific explanation and justification.
3. On the basis of the two previous points, 'revisiting' some defining aspects of school scientific argumentation with an epistemic perspective, using categories from HPS that may help in the re-conduction of this issue towards convergence with the area of research of this handbook.

As stated above, the current state of development of the emerging line of research around argumentation within didactics of science is impressive, with several hundreds of papers accumulated (cf., Osborne et al. 2012). Consequently, this chapter does not purport to be a comprehensive literature review in all aspects of argumentation,[10] but rather an account of some productions on school scientific argumentation selected due to their possibility to be 'tuned' to the discussions in our own field, HPS. At the same time, the chapter makes an effort to incorporate into the English-speaking discussion in science education some less visible contributions from the continental, 'Didaktik' tradition (cf., Westbury et al. 2000), to a great extent shared by Germanic, Scandinavian, Latin, Greek and Slavic countries.

## 45.2 The Notion of School Scientific Argumentation

In this chapter, I call 'school scientific argumentation' (cf., Adúriz-Bravo 2011) the argumentative *processes* (i.e. discursive practices) and *products* (i.e. texts in any semiotic register) that occur in the science classrooms of all educational levels – from Kindergarten to University. In this sense, 'argumentation' here refers both to argu*ment* and argu*ing*, i.e. 'the product, statement or piece or reasoned discourse […] and […] the social process or activity' (Jiménez-Aleixandre and Erduran 2008, p. 12).

[10] The tables of content of the three available *handbooks* on school scientific argumentation (i.e. Buty and Plantin 2008a; Erduran and Jiménez-Aleixandre 2008; Khine 2012) can give readers an idea of the current lines of research within the strand. These lines would be, once chunked and retitled, argumentation, learning and concept formation; argumentation, learning environments and communities of practice; argumentation, discourse and language games; argumentation, social interactions and meaning negotiation; argumentation and scientific reasoning; argumentation and socioscientific and moral issues; argumentation and science teacher education; argumentation-based instruction; argumentation quality and assessment; and argumentation and epistemic criteria and practices.

From now on, the chapter will be restricted to the argumentation intentionally generated so that students understand and use scientific theories and models for problem-solving within the boundaries of science. What we can call 'socioscientific argumentation' will thus be purposefully excluded, since such kind of argumentation has epistemological traits that cannot be totally captured with the elements discussed in this chapter.[11] Among those special traits of socioscientific argumentation, the following could be mentioned: (a) it is heavily context dependent; (b) it usually results from a co-construction by different utterers; (c) it draws upon moral reasoning; and (d) it does not have as main reference 'the scholarly societies acknowledged to create and validate scientific knowledge' (Tiberghien 2008, p. xi), but rather social representations and knowledge from different disciplined and undisciplined sources.

The installation of school scientific argumentation as a central issue of science education can be attributed to what may be seen as an 'argumentative turn'. That is to say, in the last four decades or so, social sciences, and social interests and debates more generally, seem to be moving in the direction of recognising argument and arguing as key features of our post-modern culture in general and of science in particular. Within the argumentative turn, at least three fields that are important for the endeavours of our community of didacticians of science are shifting towards the consideration of the nature of science as strongly argumentative (cf., Adúriz-Bravo 2010):

1. Firstly, new school science curricula point at scientific argumentation as one of the central competencies to be achieved during compulsory education (cf., Buty and Plantin 2008b; Jiménez-Aleixandre and Federico-Agraso 2009). True citizenship is now being characterised by the ability to engage in (socio-)scientific argumentation and to make informed decisions in fields such as environment, climate, energy, sustainability, public and individual health, food and pollution. It could be argued that these curricula express the current social expectations (i.e. the 'social imperative' of which Archila [2012] talks) on the education of critical citizens.
2. Secondly, meta-sciences (philosophy, history and sociology of science) and other metatheoretical perspectives have turned towards the study of the scientific language and have directly challenged the received view that considers it an *ex post facto* labelling system that operates after clear and distinct ideas and concepts have been construed. The language of science is now 'problematised'; it is seen as a rich and complex set of cultural tools that enable semiosis: giving meaning to the natural world and making sense to the users (cf., Sutton 1996, who speaks about language as an 'interpretive system'). Within this context, where a 'linguistics of science' is emerging, argumentation is considered a paradigmatic genre in science.

[11] For authoritative works on argumentation in connection with socioscientific issues, see Zeidler (2003, especially Chaps. 3, 4, 5, and 7) and Sadler (2011, especially Chaps. 11 and 12).

3. And thirdly, with direct bearings to the corpus of knowledge examined in this chapter, didactics of science and other educational studies (learning psychology, classroom ethnography, etc.) have been paying increasing attention, at least in the last 15 years, to the so-called cognitive-linguistic ability (cf., Sanmartí 2003) of scientific argumentation, analysing 'argumentation discourse in science learning contexts' (Jiménez-Aleixandre and Erduran 2008, p. 4). The science classroom is now depicted as a cultural system where language has a structuring function and thus 'talking science' (cf., Lemke 1990) should be turned into content to be explicitly and specifically taught.

It could be contended that the first of these three fields – new curricula that express new social mandates – has installed argumentation as a central issue for science education; the second field – metatheoretical studies on the language of science – has enriched our image of the nature of science by acknowledging the existence of argumentative games; and the third field – educational studies on argumentation – has equipped didactics of science with theories and methods, and it has at the same time promoted the over-emphasis on the discursive aspects.

Consistent with this prior analysis, it is the contention here that the notion of school scientific argumentation can be broadly characterised through resorting to the idea of evidence; it can then be more concretely defined using a distinct linguistic stance, and, afterwards, it can be inspected from a metatheoretical perspective, ascertaining its participation in the construction of science.

For a broad definition, this chapter resorts to Jiménez-Aleixandre and Díaz de Bustamante (2003), who see scientific argumentation as 'the ability to relate data and conclusions, to evaluate theoretical propositions in the light of empirical data or data from other sources' (p. 361, my translation).

The term 'evidence' will be used here to designate not only empirical data arising from observation and experimentation but also theoretical reasons, authoritative claims, elements from worldviews, ethical considerations, stakeholders' interests and other kinds of 'supporting assertions'.[12] Thus, evidence collectively denotes the *grounds* provided to justify the assertion or claim that is being argued for:

> Evidences are the observations, facts, experiments, signs, samples, or reasons with which we intend to show that a statement is true or false. (Jiménez-Aleixandre 2010, p. 20; my translation)

This initial, general, characterisation identifies scientific argumentation as one of the basic processes of knowledge construction, a process that

> recasts the role of evidence and data in scientific classrooms: rather than being used to demonstrate the scientific canon or even to guide students to construct correct scientific principles, it is the grounds on which claims – generated by students in the process of argumentation – are warranted. (Atkins 2008, p. 63)

[12] A conception of evidence that is broader than 'experimental data' on the one hand better captures the history of scientific activity and on the other hand is essential in order to account for argumentation in socioscientific contexts.

This approach to argumentation represents a sophistication of the definition presented in Sect. 45.1, at least in the line of its first highlighted element – 'arriving at conclusions […] through a process of logical reasoning' – as it underlines the *functional* role played by evidence in the derivation of such conclusions.

For a more specific definition, it is useful to adhere to the one presented by the research group LIEC (*Lectura i Ensenyament de les Ciències*, 'Reading and Science Teaching') from the Universitat Autònoma de Barcelona in Spain:

> Argumentation is a social, intellectual, and verbal activity that allows justifying or rebutting a claim; it consists of making statements taking into account the recipient and the aim with which they are transmitted. In order to argue, one must choose between different options or explanations and reason the criteria that permit evaluating the chosen option as the most adequate. (Sanmartí 2003, p. 123; my translation)

According to this strongly linguistic approach, arguing would then be elaborating a text (be it oral, written or multi-semiotic) with the aim of changing the epistemic value of the ideas sustained by an audience (or a single recipient) on an issue or matter. Such a change is sought through providing meaningful reasons so that the audience or recipient see that a new set of ideas is 'justified' by evidence in its most general sense, introduced above. The weight attributed here to justifying and convincing to some extent mirrors the other two highlighted elements of the definition in Sect. 45.1: 'a process […] that includes debate and persuasion'.

This theoretical conceptualisation on scientific argumentation, and a host of others to which didactics of science has resorted, stem from 'a range of relevant disciplines' (Bricker and Bell 2008, p. 474). According to Bricker and Bell's (2008) classic article, the most relevant of such disciplines are formal logic, argumentation theory, science studies (and here the philosophy of science would be included) and the 'learning sciences'. The next paragraphs draw on the contributions of the first three, which are more pertinent for an HPS approach.

In order to characterise scientific argumentation from a didactical point of view, some 'tensions' (cf., Adúriz-Bravo 2010) that underlie the notion of argumentation – within and outside the science classroom – need to be discussed; such tensions are unveiled when analytical tools from the aforementioned disciplines are employed. It could be safely said that these tensions have many times been dismissed or underrepresented in the literature of didactics of science, partly perhaps as a result of the hegemony of the so-called Toulmin's argumentation pattern (or 'TAP') as the preferred theoretical and methodological framework (see Sect. 45.2.1). The generalised use of TAP has fixed the discussion around semiformal reconstructions of arguments akin to those propounded by the theory of argumentation of mid-twentieth century or, rather, around a highly stylised didactical version of such reconstructions.

The four tensions that are developed in the following subsections are:

1. The opposition between two intellectual traditions to study argumentation, namely, the *Anglo-Saxon* (e.g. Stephen Toulmin, Henry W. Johnstone Jr., Ralph H. Johnson, Douglas Walton, G. Thomas Goodnight) and the *continental* (e.g. Arne Naess, Chaïm Perelman, Oswald Ducrot, Frans van Eemeren & Rob

Grootendorst, Christian Plantin).[13] These two traditions would represent complementary ways of going beyond the classical, neo-Aristotelian, approach to the study of arguments: in the first case, by 'softening' the requirements of syllogistic logic, and in the second, by opening the floor to pragmatic and rhetorical constraints.

2. *Logic* versus *dialogic* argumentation. The opposition between two extreme forms of argumentation – argumentation as explanation and argumentation as debate – is traditionally presented as the existence of 'analytical' and 'dialectical' arguments.[14] Such opposition is usually conflated with the distinction between the use of formal and informal logic in order to analyse such arguments, revised in the fourth tension.
3. Arguing as *explaining* versus arguing as *justifying*, partially connected to the former, and pointing at Jiménez-Aleixandre and Erduran's (2008, p. 9) distinction between producing scientific knowledge about the world and giving 'rhetorical significance' to that knowledge. The 'explanatory' part of argumentation, in this context, would entail making sense of a phenomenon on the basis of data, while the 'justification' part would mean supporting the claim that the data are consistent with the proposed explanation and therefore convincing an audience of its validity (cf., Osborne and Patterson 2011, p. 629, who use similar phrasings, but sharply separate these two operations).
4. Arguments as texts of *'harder'* versus *'softer' syntax*. This refers to the clash between the existence of sanctioned patterns with an a priori rationality dictated by formal logic, leading to heavily 'idealised notions of arguments' (Jiménez-Aleixandre and Erduran 2008, p. 15), and the pragmatic use of what we can call *para-logical* (i.e. ampliative) techniques to capture argumentation 'as it is practiced in the natural languages' (Jiménez-Aleixandre and Erduran 2008, p. 14). Among these 'real' argumentative practices, scientists', teachers' and students' discourse would be included.

### *45.2.1 Anglo-Saxon Versus Continental Approach to Argumentation*

Since the three traditions that follow this first one can be said to hinge to some extent on an *ab initio* divergence between theoretical approaches to argumentation, this subsection is longer and more detailed than the rest; in those, cross-references to the ideas exposed here are made.

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[13] For other authors not mentioned in this list, see Reygadas and Haidar (2001), Santibáñez (2012).

[14] This opposition is in turn based on Aristotle's division of 'perspectives' on argumentation that has been thoroughly used in continental studies and retrieved by the Anglo-Saxon tradition: logical, dialectical and rhetorical (cf., Harpine 1985; van Eemeren and Houtlosser 2003). The chapter concentrates only in the first two classes of arguments.

The Anglo-Saxon tradition in argumentation studies was long based on the assumption that arguments are more or less 'syllogistic' (i.e. deductive-like) in nature (this restrictive requirement of 'deductivity' is still retained in the general definition of argumentation presented in Sect. 45.1). Arguments were usually portrayed as a tight structure in which a key assertion is logically inferred from a set of supporting assertions (Asti Vera and Ambrosini 2010). As Stephen Toulmin critically remarks,

> [T]he assumption […] made by most Anglo-American academic philosophers [was] that any significant argument can be put in formal terms: not just as a syllogism, since for Aristotle himself any inference can be called a 'syllogism' or 'linking of statements', but a rigidly *demonstrative deduction* of the kind to be found in Euclidean geometry. Thus was created the Platonic tradition that, some two millennia later, was revived by René Descartes. (Toulmin 2003, p. vii; my emphasis)

Accordingly, classical argumentation theory among Anglo-Saxon authors more or less overlapped in scope and methods with the discipline of logic – the main aim being to ascertain the *validity* of arguments using formal techniques.

In the Anglo-Saxon tradition, the main connecting threads would be the attention paid to the *syntactic* aspects of the language used to argue and the aim of analysing individual propositions and their structural relations in order to justify and assess theoretical arguments, dialogic exchanges and informed judgements set against the backdrop of their social contexts. The evolution of this tradition could be seen as an expansion of the traditional apparatus to study argumentation – which strictly resorted to formal logic – towards the use of 'para-logical' tools, moving then onto 'informal logic'. The focus is thus to capture 'natural' arguments, to formulate

> [the] statements [referred to in those arguments] in a 'normal' (philosophical, universal) language in some canonical form [, since a]fter 2,300 years of formal logic, [argumentation theory is] still infinitely remote from having a clear idea of what such a language should look like. (Bar-Hillel 1970, p. 204)

This Anglo-Saxon approach to argumentation will be here characterised through rapidly examining the work of the British-born philosopher of science Stephen Toulmin, with a peripheral mention to the Canadian argumentation theorist Douglas Walton and the American educational psychologist Deanna Kuhn.

Toulmin's (1958) framework hinges upon a naturalistic approach to the rationality of practical arguments (which he calls 'substantial' arguments). Substantial arguments are opposed to 'theoretical' arguments, which are analytic and necessary. This means that, in the latter, the argued assertions are the conclusions of *sensu stricto* inferences; such assertions are deductively connected to a set of premises providing the evidence for it (hard data or other grounds, but always satisfying the relationship of logical necessity with the conclusion). Thus, what is being sustained is already 'contained' in what we know.

Substantial arguments, on the contrary, seek to offer 'justification' for an assertion that is deemed to be of interest, in a specified and recognisable context. Thus, Toulmin suggests going beyond formal logic when modelling arguments and proposes an 'argumentation pattern' with tightly interrelated components:

the *claim* (which is the statement in need of justification), *data* to support such claim and a *warrant* that allows the 'legitimate' transition from data to claim. Even more 'real' arguments in the natural language are heavily modalised and include qualifiers, rebuttals and backing to the warrant.

It could be stated that, in Toulmin's framework, the claim – 'conclusion' *sensu lato* – has more content than that of the evidences provided, and thus it is only partially sustained by them. Accordingly, it is convenient to portray the 'movement' from the premises containing the evidence to the conclusion as an ampliative inference, which should be captured with inductive, analogical, abductive, etc. reasoning patterns (cf., Stadler 2004; Diéguez Lucena 2005).

In turn, the goal of Walton's (1996) framework is more related to understanding persuasive arguments, for example, in legal contexts. Walton is thus more interested in *dialogic*, conversational argumentation (see next subsection), where 'actors exchange replies and counter-replies' (Asti Vera and Ambrosini 2010, p. 133; my translation). Walton's *schemes* for 'presumptive reasoning' refer to strategies used in hypothetic, non-demonstrative, argumentation. To capture those schemes, he enumerates a variety of categories; for instance, he talks about 'arguments based on experts' opinions', which might be instrumental both for scientists' science and school science. *Pertinence* of the utterances – and of the reasons given therein – is a key theoretical element of his framework.

As a complement to the general Anglo-Saxon perspective, D. Kuhn (1993, 2010), moving markedly away from philosophical and linguistic considerations, proposes a conceptualisation of science and of science education as argumentative endeavours that resorts to psychological and cognitive foundations. In this sense, she is a good example of contributions to argumentation from the 'learning sciences'.

Opposing the Anglo-Saxon tradition, we can talk of a 're-emergence' of a continental approach to argumentation studies, which occurs after World War II and is of course favoured by external, socio-cultural, factors (cf., Jiménez-Aleixandre and Erduran 2008). Chaïm Perelman's life story – he was a Polish Jew who immigrated to Brussels – is a good example of this. The continental tradition will here be represented in the works of the expert in rhetoric Perelman, the Dutch scholars in 'speech communication' Frans van Eemeren and Rob Grootendorst and Christian Plantin. The connecting threads of this tradition would be the introduction of the audience as a key element and the attention to pragmatic and rhetorical aspects.

Perelman publishes, together with Lucie Olbrechts-Tyteca, his *Traité de l'argumentation* in 1958 (the same year of Toulmin's *The uses of argument*). In this book, the authors propose a 'new rhetoric', understood as an art of persuading and convincing; with this, they also intend to abandon formal logic in the evaluation of argument validity. But, differing from the Anglo-Saxon perspective, persuasion is highlighted; in order to characterise arguments, Perelman constructs new concepts around this idea, such as argumentative force and relevance or the 'intensity of adherence of an audience'. The introduction of the audience as 'a genuine actor in the argumentative phenomenon' (Asti Vera and Ambrosini 2010, p. 110; my translation) is generally considered to be Perelman's main contribution.

Van Eemeren and Grootendorst, at the Universiteit van Amsterdam, develop what they call a *pragma-dialectical theory* of argumentation; like Perelman, they seek to analyse and assess argumentation as a natural practice of language. Pragma-dialectics takes into account the fact that arguments are usually presented within interactive, dialogic discussion. These authors also confront the use of syllogistic structures to study argumentation, since formal logic would be opaque to the subtleties of the social practice of arguing. Scientific argumentation would also need this approach, since scientists direct their arguments to convince peers (or other audiences) so that they accept the point of view that is being offered. Carlos Asti Vera and Cristina Ambrosini (2010) recognise a very 'fecund' starting point in pragma-dialectics, since 'it proposes not abstracting arguments of any of their dimensions, in order to analyse and evaluate them as they are presented in the social theatre, in their empirical, dialogic and contextual determinations' (p. 133).

Plantin is also interested in a rhetorical study of dialogic argumentation (he calls it 'dialogale' in French: cf., Plantin 2011) and again focuses on persuasion as one of its central characteristics. He interprets argumentation as a way of producing speech in situations where doubt, debate and confrontation predominate. It is interesting to remark that Plantin wants to redeem rhetoric from its reputation as a 'sorceress' (Buty and Plantin 2008b, p. 21); according to him, rhetoric has been stereotypically discredited, being repeatedly associated with manipulation, void words and politicians' clichés (for these he uses the very graphic French expression of 'langue de bois').

### *45.2.2 Logic Versus Dialogic Argumentation*

What I call 'logic argumentation' – where arguments are practically confounded with explanations or inferences – can be described, using Richard Duschl's terminological choices (cf., Duschl et al. 1999; Duschl 2008), as the production of analytical arguments. These arguments are grounded in (formal) logic, and they constitute a movement from a set of premises to a conclusion (cf., Asti Vera and Ambrosini 2010). What I call 'dialogic argumentation' – where arguing is seen as exchange of ideas or confrontation – fits with the idea of dialectical arguments, which are 'those that occur during discussion or debate and involve reasoning with premises that are not evidently true' (Duschl 2008, p. 163). It could arguably been said that it was in order to understand this latter kind of arguments that the field of (new) argumentation theory emerged in the 1950s, somewhat vanishing its boundaries with informal logic.

This broad distinction made under this tension can be related to the two major scholarly approaches to argumentation in Sect. 45.2.1 as follows: the stereotypical Anglo-Saxon approach was almost restricted to analytical arguments and logic argumentation (as is apparent in Toulmin's critique), while the best-known continental frameworks over-emphasised dialectical arguments and dialogic argumentation. This simplified, one-to-one relationship tends to relax in more recent texts.

For didactical purposes, it seems convenient to blur this watertight distinction and consider that school scientific argumentation combines in itself the long-standing Greco-Latin traditions of arguing as producing 'any piece of reasoned discourse' (Jiménez-Aleixandre and Erduran 2008, p. 12) and arguing as 'dispute or debate between people opposing each other with contrasting sides to an issue' (Jiménez-Aleixandre and Erduran 2008, p. 12). Thus, on the logic side, argumentation evokes the etymological meaning of the Latin verb 'arguere': 'make clear through discourse'; such meaning stems from the Indo-European root 'arg-', meaning 'brilliant' (conserved in modern terms such as the Italian 'argento', 'silver' or the French 'argille', 'clay'). On the dialogic side, argumentation points at one of the standard meanings of the English verb 'argue': 'discuss', 'dispute' and 'disagree'. But these two aims of clarifying and debating coexist – and are virtually impossible to divorce from each other – in the language game of argumentation in science.

### *45.2.3 Arguing as Explaining and Arguing as Justifying*

When argumentation is seen as a vehicle for scientific explanation, the emphasis is put on the sharing of theoretical elements that permit us to understand the world. Arguments are seen as 'solid', i.e. with a claim well supported by foundations and backings (cf., Asti Vera and Ambrosini 2010), and such a view purports to be context and audience independent.[15] In this first perspective, Toulmin's idea of warrant is paramount: warrants serve as the explanatory elements; their aim is to give testimony of the legitimacy of the transition from data to claim. Warrants provide general, abstract and *uniform* transitions, which are relatively autonomous of (i.e. not referring directly to) particular sets of data.

When argumentation is seen as an act of speech where justification is demanded and offered (cf., Tindale 1999, who examines this idea based on Michael Billig and Chaïm Perelman), the focus is moved to the recipient's or audience's adherence to the claim presented. In this second perspective, more akin to continental studies, 'argumentation is a feature of social relations and shares in the complexity of those relations' (Tindale 1999, p. 75).

In science education, the distinction between argumentation as explanation and argumentation as justification can be partially aligned with what Nussbaum and colleagues (2012) call the 'two faces of [school] scientific argumentation'. According to these authors, argumentation is on the one hand *explanatory*, when it presents and debates scientists' theories about reality. On the other hand, argumentation is *prescriptive*, when it informs scientific (and socioscientific) debates, where decision-making is often required. These authors distinguish between 'theoretical discourse, pertaining to what theories of the world best fit the data and practical, deliberative discourse, regarding how to apply those theories to reach practical goals' (Nussbaum

[15] This is what Constanza Padilla (2012) calls 'demonstrative dimension' of argumentation.

et al. 2012, p. 17). Accordingly, students and teachers together would use scientific arguments in the science classroom to explain theoretically *and* to circulate and share understandings and applications.

### *45.2.4 Hard and Soft Arguments*

This last tension, as advanced above, has to do with the capacity attributed to formal, abstract structures to capture real discourse. The classical, positivistic approach of categorical rationalism 'supposes enthroning formal logic as the *exclusive* model of rationality' (Asti Vera and Ambrosini 2010, p. 110; my translation, emphasis in the original). Through the lens of formal logic, only what we might call 'hard arguments' survive: those that are 'fully explicit [and] neatly packaged into premises and conclusions' (Smith 2003, p. 34).

If one adheres to this restriction, real argumentation practices are almost always subsumed into the realm of material (or informal) fallacies. There is an *ab initio* 'half-empty glass' metaphor operating here, since – from the point of view of hard rationality – most arguments are considered to be logically non-pertinent, only psychologically persuasive, and often intended to deceive (cf. Asti Vera and Ambrosini 2010). Even in the case of (empirical) science, most relevant arguments do not measure up to the extremely restrictive standards of demonstrative argumentation, since they contain in their fabric elements that are not bound by the relationship of necessity, and therefore cannot be completely formalised without consideration of their empirical content.

Two options arise to oppose this 'hard' approach: in the first place, rationality can be resigned altogether, slipping down the irrational slopes of contextualism, relativism or constructivism. A 'third way', which seems more productive for science education, would be to broaden the scope of arguments that can be considered well supported. This third way would imply a 'temperate', non-aprioristic, rationality, which resorts to the use of 'para-logical' techniques, i.e. non-demonstrative patterns of inference such as induction or abduction. Softening the syntax admitted for arguments is, in all cases, allowing a richer study of argumentation as it occurs in the real world. This would constitute a *naturalisation* of argumentation theory.

For this last tension, the link to the Anglo-Saxon-continental dispute is not straightforward. One might be tempted to assume that the Anglo-Saxon approach closes up the number and variety of patterns of argumentation that are admissible and is therefore more identifiable with the idea of 'harder syntax'. This might be the case for the classical studies, those that fall under Toulmin's critique, but it is certainly not applicable to post-Toulminian accounts of scientific argumentation among English-speaking scholars. On the other hand, a pairing of what I have proposed to call 'softer syntax' to continental accounts would be too hasty, since the examination of the structure and components of an argument is seldom a concern among authors who zoom out to rhetorico-pragmatic considerations.

## 45.3 The Epistemics of School Scientific Argumentation

This section is devoted to dissecting some of the epistemic aspects of school scientific argumentation, aspects that can be theorised through the lens of HPS.[16] The section discusses different constituting elements of the *epistemics* (i.e. epistemology) of argumentation, identified on the basis of a review of the literature in didactics of science that is heavily theory driven. That is to say, the review is guided by an attention to metatheoretical perspectives and especially to the philosophy of science. As it was advanced in the introduction to the chapter, in order to organise such review, possible 'bridges' between argumentation and HPS are defined.

Under the five bridges enumerated here, studies on school scientific argumentation with an interest in one or more particular epistemic aspects are grouped. The studies may or may not present an explicit HPS background, and this will be indicated for each case. The five resulting groups are:

1. *Argumentation as an epistemic practice.* In this first approach, undoubtedly the most exploited one, the bridge consists in identifying argumentation as a paradigmatic example of epistemic practice, i.e. a practice of knowledge construction that gives its character to the scientific activity. Richard Duschl (1998, 2008), Marilar Jiménez-Aleixandre (Jiménez-Aleixandre and Federico-Agraso 2009; Bravo-Torija and Jiménez-Aleixandre 2011), Gregory Kelly (Kelly and Chen 1999; Kelly and Takao 2002), Victor Sampson and Douglas Clark (2006, 2008), and William Sandoval (Sandoval 2003; Sandoval and Reiser 2004; Sandoval and Millwood 2005, 2008), among many others, have advocated for a conceptualisation of argumentation along this line.
2. *Argumentation as a feature of the nature of science.* In this second, more encompassing approach, the bridge consists in describing the 'non-natural' nature of science,[17] at least partially, through inspecting the role that argumentation (both in the senses of explaining and of justifying) plays in doing, thinking and talking about the natural world. Authors who can be located within this perspective[18] identify science not with the 'discovered' facts of the world, but rather with an extremely elaborate inferential and discursive construction regarding the ways in which scientists appropriate and transform those facts.
3. *Argumentation in scientific inquiry.* In this third approach, school science is designed as an inquiry-based endeavour aiming at genuine scientific literacy (see public policy documents such as AAAS 1993; NRC 1995). The bridge here

[16] The name of this section is a paraphrasis of an expression by Sandoval and Millwood (2008, p. 72).

[17] Both Lewis Wolpert (1992) and Lydia Galagovsky (2008) refer to this 'non-naturality' of science in the titles of their books. Nevertheless, the meanings of the expressions that they use are quite distinct from each other. Wolpert's thesis, positivistic in its foundations, is that science is a way of thinking far away from common sense. Galagovsky's compilation of chapters aims at showing how science is a very elaborate human construction and not a mere expression of the way the world is.

[18] For example, Allchin (2011), Duschl (1990, 1998), Hodson (2009), Lawson (2003, 2005, 2009), and McDonald (2010)

is the attention to the inclusion of argumentative skills in such an endeavour. A grasp of the nature of science in science education

> involves understanding *how knowledge is generated, justified, and evaluated* by scientists and *how to use such knowledge to engage in inquiry* in ways that reflect the practices of the scientific community. (Clark et al. 2010, p. 1; emphasis in the original)

The two elements of the nature of science italicised in this quote could be somehow referred to the two poles of tension 3: on the one hand, students need to comprehend the epistemic practice of knowledge generation (explanation); on the other hand, students need to apply that knowledge in school scientific inquiry (justification). Proposals along this line[19] strive to meaningfully connect argumentation and inquiry through the introduction of evidence- and argument-based practices in the science classroom.

4. *Model-based argumentation.* In this fourth approach,

> the general model-based perspective in […] the philosophy of science [is used in order to] understand arguments as reasons for the appropriateness of a theoretical model which explains a certain phenomenon. (Böttcher and Meisert 2011, p. 103)

The bridge here is that argumentation is regarded as a tool to assess and apply the models that constitute the content of school science. Authors who use this perspective (Adúriz-Bravo (2011), Böttcher and Meisert (2011) and much less directly Lehrer and Schauble (2006), who talk about 'model-based reasoning' and Windschitl et al. (2008), who talk about 'model-based inquiry') conceptualise models using *semantic* tools from the philosophy of science of the last three decades.

5. *Argument-based school science.* This fifth approach is rather unspecific; it suggests that argumentation should be a substantive part of the (social) activity in the science classroom (and in science teacher education). Authors adhering to this perspective talk about 'argumentation-based' teaching or instruction.[20] The bridge here are the reasons provided in favour of this position, drawn mainly from the sociology of science (with references to Helen Longino or Bruno Latour, for instance) and to a lesser extent from other metatheoretical perspectives.

A proviso should be made here: in the very biased selection of literature in which the bridges between argumentation and HPS have been identified, papers that use HPS elements for the design of instructional units and materials, but then fail to use those elements to characterise or justify the presence of argumentation in those units and materials, were purposefully excluded. For instance, Bell and Linn (2000), Monk and Osborne (1997) and Revel Chion and colleagues (2009) use the history and philosophy of science to lay the foundations for the teaching of different

[19] For example, Clark and colleagues (2010), Duschl and Grandy (2008), Sampson and Clark (2007), Sandoval and Reiser (2004), and Windschitl and colleagues (2008).

[20] Cf., Driver and colleagues (2000), Izquierdo-Aymerich (2005), Newton and colleagues (1999), Ogunniyi (2007), and Ogunniyi and Hewson (2008).

scientific topics (Darwin's ideas, light, the bubonic plague, etc.), and then – more or less independently of those foundations – they propose to implement argumentation as a teaching strategy.

In the subsections that follow, the five aforementioned bridges are explicated through one or two epitomic examples of each of them.

### *45.3.1 Argumentation as an Epistemic Practice*

Richard Duschl's work locates explanation at the vertex of the pyramid of the activities in science (cf., Duschl 1990), identifying it as a privileged aim of the scientific enterprise. In his framework, and following Gregory Kelly and Deanna Kuhn, argumentation would constitute one of the most favoured epistemic (i.e. knowledge-producing) practices. Consistent with this conceptualisation of scientists' science, Duschl proposes, for school science,

> [s]hifting the dominant focus of teaching from what we know (e.g., terms and concepts) to a foc[us] that emphasizes how we know what we know and why we believe what we know (e.g., using criteria to evaluate claims). (Duschl 2008, p. 159)

School science would then require 'epistemic apprenticeship' (Jiménez-Aleixandre and Erduran 2008, p. 9): students should appropriate criteria to evaluate arguments in the light of evidence. Accordingly, science in the classroom could be structured as a set of 'epistemological and social processes in which knowledge claims can be shaped, modified, restructured and, at times, abandoned' (Duschl 2008, p. 159). Duschl talks about 'knowledge-building rules' that represent or embody the epistemic practices of the community formed by students and teacher(s).

Thus, the core of this conceptualisation of argumentation as an exemplar of educationally valuable epistemic practice would be captured in questions such as

> What counts as a claim? What counts as evidence? How do you decide what sort of evidence supports, or refutes, a particular claim? How are individual claims organized to produce a coherent argument? What kinds of coordination of claims and evidence make an argument persuasive? (Sandoval and Millwood 2008, p. 72)

One of the most favoured strategies in the studies allocated in this first group has been to recognise epistemic *statuses*, *criteria* or *levels* in students' argumentative practice, with the aim of 'assessing the nature or quality of arguments in the context of science education' (Sampson and Clark 2008, p. 449). Such assessment is done, for instance, in terms of their complexity, robustness, validity, etc.

For this first bridge, explicit recurrence to authors from the area of HPS has been somewhat low. In Sandoval and Millwood (2008), for instance, of almost 30 cited references, only three are to authors with a meta-scientific perspective: Philip Kitcher, Bruno Latour and Stephen Toulmin. In Duschl (2008), of around 45 cited references, again only three are to texts in the realm of HPS (Derek Hodson, Nicholas Rescher and Toulmin). In Sampson and Clark (2008), among circa 65 references, only two 'meta-scientists' feature: Latour and Thomas Kuhn. The relationship between favouring argumentative practices in science education and metatheoretically characterising those as epistemic practices is therefore *indirect*: most authors that develop this first bridge refer to some seminal texts in didactics of science (e.g. Driver et al. 2000; Duschl and Osborne 2002; Kelly and Takao 2002) that have acknowledged the philosophical foundations of that relationship, but then do not go on developing such foundations.

### 45.3.2 Argumentation as a Feature of the Nature of Science

There is a substantive connection between this second approach and the first one, since a widespread hypothesis in science education considers that 'students' epistemological beliefs [i.e. their conceptions on the nature of science] are developed through their own epistemic practices of making and evaluating knowledge claims' (Sandoval and Millwood 2008, p. 85). Epistemic practices in general, and argumentation in particular, would then be, at the same time, a specific feature of the nature of science (cf., Hodson 2009, Chap. 8) and a powerful means to access to a coherent and robust conceptualisation of such nature.

Both Jonathan Osborne and Sibel Erduran, in many of their papers (cf., Erduran et al. 2004; Osborne et al. 2001), have enumerated different links between the nature of science and argumentation. Osborne and colleagues (2001), for instance, subordinate those links to the need to teach the nature of science *explicitly*,[21] since 'contact with school science is insufficient to generate an understanding of how science functions' (p. 69). For such teaching, argumentation becomes a privileged tool, insofar as it permits presenting students with opportunities to examine and discuss epistemological issues such as evidence, prediction, analytical thinking, controversy, reasoning, evaluation and critical thinking.

From a more focussed point of view, Anton Lawson points out that nature-of-science instruction should teach to science students 'that the best [scientific] argument considers all of the alternatives and explicitly includes the relevant evidence and reasoning supporting and/or contradicting each' (Lawson 2009, p. 337). He suggests introducing, in science education, what he calls an 'if/then/therefore' argumentative pattern. His theoretical framework, which he deems valid both for scientists' science and for school science,

> distinguishes among an argument's declarative elements (i.e., puzzling observations, causal questions, hypotheses, planned tests, predictions, conducted tests, results, and conclusions) and its procedural elements (i.e., abduction, retroduction, deduction, and induction). (Lawson 2009, p. 358)

[21] As one of the anonymous reviewers of this chapter pointed out, considering the nature of science or argumentation important goals of science education does not imply deciding to teach these issues explicitly. The contention that school scientific skills are not developed by 'exposure' and deserve 'direct instruction' is still debated; nevertheless, such contention seems to be finding some support coming from recent empirical studies (e.g. Kirschner et al. (2006), at a general level, and McDonald (2010), for the case of nature of science and argumentation).

It should be noted that Lawson provides extensive HPS backing to his framework, using the history of science in order to construct case studies of scientific reasoning, argumentation and discovery and – to a lesser extent – the philosophy of science to understand those three processes.

In my own work, I portray scientific argumentation as the textual counterpart of the epistemic operation of scientific explanation (Adúriz-Bravo 2005, 2010, 2011). I define argumentation as the *subsumption* of some phenomenon of the natural world under a theoretical model (in the sense of the semanticist family), which is seen as a good candidate to 'explaining' it (and hence there is direct connection with bridge 4). Similarly to Lawson, my argument is that some discoveries and inventions, as reported by scientists through history, can be reconstructed as cases of abductive and analogical thinking; these kinds of inferences would then be the mechanism to subsume the 'phenomenon-case' under a 'model-rule'. I distinguish between abduction *sensu lato*, as any ampliative, non-monotonic, inference producing or evoking hypotheses and abduction *sensu stricto*, as a 'reverse' deductive schema *à la* Peirce (cf., Adúriz-Bravo 2005; Aliseda 2006; Samaja 1999).

### *45.3.3 Argumentation in Scientific Inquiry*

School scientific inquiry can be broadly conceptualised as a 'knowledge building process in which explanations are developed to make sense of data and then presented to a community of peers so they can be critiqued, debated and revised' (Clark et al. 2010, p. 1). In this sense, inquiry would function as a reconciliation of the two poles of the second (logic-dialogic) and third (explain-justify) tensions. Within this framework of ideas, argumentation nicely fits when understood as

> the ability to examine and then either accept or reject the relationships or connections between and among the evidence and the theoretical ideas invoked in an explanation or the ability to make connections between and among evidence and theory […]. (Clark et al. 2010, p. 1)

From this perspective, argumentation is seen as an artefact to develop and evaluate explanations (cf., Kuhn Berland and Reiser 2009; Osborne and Patterson 2011; Windschitl et al. 2008). In other words, in this third approach the practices of explanation and argumentation would be *complementary*:

> First, explanations of scientific phenomena can provide a product around which the argumentation can occur, as proponents of an explanation attempt to persuade their peers of their understandings. Second, argumentation creates a context in which robust explanations – those with which the community (the students) can agree – are valued. (Kuhn Berland and Reiser 2009, p. 28)

For this third bridge, it should be noted that Kuhn Berland and Reiser's (2009) paper has an extensive and developed HPS background. These authors show how several philosophers of science, in the last six decades, extended

> [t]he everyday sense of argumentation[, which] typically suggests a competitive interaction in which participants present claims, defend their own claims, and rebut the claims of their

> opponents until one participant (or side) “wins” and the other “loses”. [Instead, i]ndividuals compare conflicting explanations with the support for those explanations and work to identify/construct an explanation that best fits the available evidence and logic. (Kuhn Berland and Reiser 2009, pp. 27–28)

### 45.3.4 Model-Based Argumentation

In model-based argumentation, scientific arguments are understood as the ‘reasons for the appropriateness of a theoretical model which explains a certain phenomenon’ (Böttcher and Meisert 2011, p. 103), and argumentation ‘is considered to be the process of the critical evaluation of such a model if necessary in relation to alternative models’ (Böttcher and Meisert 2011, p. 103). Here, the second and fourth tensions are apparent: on the one hand, models that explain are judged in terms of the reasons for their justification; on the other hand, critical evaluation of the appropriateness of those models would require the use of some analytical tools arising from classical or modern logic.

Central to this approach to school scientific argumentation is the thesis that

> [t]he model-based theory represents a suitable theoretical framework for describing arguments and argumentation referring to the similarity between models and empirical data as the central reference for model evaluation. (Böttcher and Meisert 2011, p. 137)

Derek Hodson (2009) provides a detailed description of the role attributed to argumentation in a model-based depiction of the nature of science. Closely following Ronald Giere (Giere 1988; Giere et al. 2005), he states that

> [r]eaching consensus about the most acceptable model involves a cluster of interacting, overlapping and recursive steps: (i) collection of data via observation and/or experiment, (ii) reasoning, conjecture and *argument*, (iii) calculation and prediction, and (iv) critical scrutiny of all these matters by the community of practitioners. Language plays a role in all these steps […]. As an integral part of these activities, *arguments* are constructed and evaluated at a number of different levels. (Hodson 2009, p. 259; my emphasis)

Such description, explicitly based on HPS, justifies the use of argumentative strategies within the framework of model-based science education.

From a slightly different perspective, but also stressing the role of models in scientific argumentation, Jiménez-Aleixandre (2010) focuses on ‘arguments on explanatory models’, stating that such arguments intend to identify cause-effect relations in the explanations and interpretations on natural phenomena.

### 45.3.5 Argumentation in School Science

School scientific argumentation is brought to the centre of the arena of teaching practices (‘pedagogy’) when the pre-eminently *empirical* conception of students’ activity in the science classroom is abandoned in favour of a more theory-laden, social and discursive depiction of school science. Rosalind Driver and her colleagues (2000) accurately explain this shift in the following quote:

> Our contention is that, to provide adequate science education for young people, it is necessary to reconceptualize the practices of science teaching so as to portray scientific knowledge as socially constructed. This change in perspective has major implications for pedagogy, requiring discursive activities, especially argument, to be given a greater prominence. Traditionally, in the UK (and other Anglo-Saxon countries), there has been considerable emphasis on practical, empirical work in science classes. Reconceptualizing the teaching of science in the light of a social constructivist perspective requires, among other matters, the reconsideration of the place of students' experiments and investigations. Rather than portraying empirical work as constituting the basic procedural steps of scientific practice (the "scientific method"), it should be valued for the role it plays in providing evidence for knowledge claims. (Driver et al. 2000, p. 289)

In Mercè Izquierdo-Aymerich's work,[22] argumentation is incorporated as a central feature of her general theoretical framework for didactics of science (developed with colleagues at the Universitat Autònoma de Barcelona). She labels such framework, following Ronald Giere (1988), the 'cognitive model of school science'; this and other authors from the so-called semantic view of scientific theories in contemporary philosophy of science provide her with the conceptualisation of theoretical models that she deems to be most fruitful for science education (and hence the intersection with bridge 4).

Within this framework, school scientific arguments are cognitive and discursive tools that permit making meaningful connections between the realm of facts in the world and the models that can give meaning to those facts:

> Students reason according to their initial models, which generally have an *iconic* relationship with phenomena; a simple image may function as a model for students. Experimentation and its written reconstruction bring students to a new epistemic level, in which non-iconic (i.e., *symbolic*) signs are much more relevant. Symbols can only connect correctly with their referents if the first, more concrete step is done […]. In order to give momentum to this process, it is necessary that students learn how to use argumentation in their discourse […]. (Izquierdo-Aymerich and Adúriz-Bravo 2003, p. 38; emphasis in the original)

## 45.4 Conclusion: Towards Convergence of Argumentation with HPS

The purpose of this short conclusive section is to revisit six characterisations of school scientific argumentation with the ideas provided by an HPS-informed approach, which were discussed throughout this chapter. For each of the excerpts revisited, connections with the five bridges are made, and some HPS references (mainly from the philosophy of science) are suggested that could help in furthering the discussion only sketchily initiated here.

[22] See Izquierdo-Aymerich (2005), Izquierdo-Aymerich and Adúriz-Bravo (2003), and Izquierdo-Aymerich and colleagues (1999).

Sampson and Clark (2008) propose to use 'the term «argument» to describe the artefacts students create to articulate and justify claims or explanations and the term «argumentation» to describe the complex process of generating these artefacts' (p. 448). This first terminological clarification reminds us of the fact that in order to fully understand school scientific argumentation, we should consider it as *a product that arises from a highly elaborate process and is therefore shaped by the very nature of that process*. Here the connection with bridge 1 is direct: an epistemic characterisation of the argumentation process is required, be it more 'internalist', focussing on inferences (e.g. Charles Sanders Peirce, Stephen Toulmin or Nancy Nersessian) or more 'externalist', looking at social interactions within the scientific communities (e.g. Thomas Kuhn, Bruno Latour or Helen Longino).

Marilar Jiménez-Aleixandre (2010) starts her book on key ideas about argumentation with a working definition of the notion; she considers it the 'ability to relate explanations and evidences' (p. 11, my translation). In this kind of phrasing, the evidence-based character of the scientific enterprise is highlighted: *evidence (in its broadest sense) becomes a key epistemic factor, one of the cornerstones of scientists' activity.* This emphasis can lead, in science education, to fruitful discussion around the notion of rationality, with questions such as what counts as 'valid' support for scientific claims, and how is this support obtained and shared? To answer such questions, related mainly to bridges 2 and 3, a postpositivistic notion of rationality can be introduced. For this kind of discussion, ideas from Stephen Toulmin,[23] William H. Newton-Smith or Ronald Giere seem appropriate.

Rosalind Driver, in one of her posthumous papers (Driver et al. 2000), advocates for a 'situated perspective', where 'argument can be seen to take place as an individual activity, through thinking and writing, or as a social activity taking place within a group – a negotiated social act within a specific community' (pp. 290–291). When arguing, *scientists give meaning to the world and communicate such meaning to peers and other audiences*; this should be a guiding idea of the nature of science discussed in the science classroom. Again, this double cognitive and social perspective can be inspected with tools from the philosophy of science and from science studies, anchoring the discussion in selected episodes from the history of science.

Anton Lawson, distinguishing himself from Toulmin's ideas on argumentation, so hegemonic in didactics of science, prefers to see

> the primary role of argumentation, not as one of convincing others of one's point of view (although that is certainly part of the story) but rather as one of discovering which of several possible explanations for a particular puzzling observation should be accepted and which should be rejected. (Lawson 2009, p. 337).

In such preference, the explanatory and theoretical aspects of argumentation are highlighted, and this might constitute a possible connection with bridge 4. Arguments *propose a way of 'seeing' the world that is structured around theoretical views*. Here, the so-called semanticist family (Giere, Frederick Suppe, Bas van

[23] Here I refer to Toulmin (2001).

Fraassen), with their various conceptualisations of scientific theories, might prove a powerful background.

Izquierdo-Aymerich and myself accept a 'relaxation' of the requirements for an argument to be considered scientific, in tune with the naturalistic approach introduced in the fourth tension:

> An argumentation is formed by a set of reasons that convey a statement and reach a conclusion. Scientific arguments are hardly ever strictly formal (logical or mathematical); they are generally analogical, causal, hypothetico-deductive, probabilistic, abductive, inductive… One of their functions is to make a theoretical model plausible, convincingly connecting it to a growing number of phenomena. (Izquierdo-Aymerich and Adúriz-Bravo 2003, p. 38)

This approach reminds us that *there is variety and richness in the language games that have been used in science through history*. Studies around the linguistics of science, especially those following Wittgenstein's ideas, may be of use to reflect on the issues posed here.

In the last characterisation of argumentation that is reviewed for this chapter, Kuhn Berland and Reiser (2011) recover the centrality of the aim of persuasion when arguing:

> The process of attempting to persuade the scientific community of an idea reveals faults in the argument (i.e., evidence that is unexplained by the idea or misapplication of accepted scientific principles), and identifying these faults creates opportunities for the community to improve upon the ideas being discussed. (Kuhn Berland and Reiser 2011, p. 212)

It can be argued that scientific disciplines are such inasmuch as they have disciples: therefore, *it is constitutive of their very nature the will to communicate, convince, persuade and teach*. This last input for science education can find support in texts from the science studies, especially in those situated in pragmatic and rhetorical perspectives.

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