Science & Education **13:** 717–731, 2004.

Methodology and Politics: A Proposal to Teach the Structuring Ideas of the Philosophy of Science through the Pendulum

AGUSTÍN ADÚRIZ-BRAVO
Departament de Didàctica de les Matemàtiques i de les Ciències Experimentals, Universitat Autònoma de Barcelona, Edifici G5, Facultat de Ciències de l'Educació, Campus UAB, E-08193, Bellaterra, España/Spain (E-mail: agustin.aduriz@campus.uab.es)

Abstract. This article refers to a framework to teach the philosophy of science to prospective and in-service science teachers. This framework includes two components: a list of the main schools of twentieth-century philosophy of science (called *stages*) and a list of their main theoretical ideas (called *strands*). In this paper, I show that two of these strands, labelled intervention/method and context/values, can be taught to science teachers using some of the instructional activities sketched in Michael Matthews's *Time for Science Education*. I first explain the meaning of the two selected strands. Then I show how the pendulum can be used as a powerful organiser to address specific issues within the nature of science, as suggested by Matthews.

Introduction

The importance of the philosophy, history and sociology of science (collectively referred to as the *nature of science*, from now on) in the science curriculum and in science teacher education has been acknowledged all over the world by educational researchers and policy makers (AAAS 1989; Matthews 1994; Driver et al. 1996; NRC 1996; Millar and Osborne 1998). Accordingly, a number of important rationales and practical proposals have been put forward in the last twenty years or so with the aim of teaching elements of the nature of science to different populations (Duschl 1990; Matthews 1991, 2000; Jiménez Aleixandre 1996; McComas 1998).

The available theoretical developments in this research line (known by its acronym NOS) generally point to the need for an identification of the epistemological foundations of science teaching. Authors usually focus on establishing connections between well-known philosophical views (e.g., rationalism, hypothetico-deductivism, revolutionism, constructivism) and models of teaching (Nussbaum 1983; Cleminson 1990; Mellado and Carracedo 1993; Izquierdo and Adúriz-Bravo 2003). As an instance of this procedure, following a critical review during the 1990s of the extensive use of constructivism in science education, some authors have highlighted the urgent need to recover *temperate* versions of realism and rationalism,[1] which are more compatible than relativist philosophies with the aims of a liberal science education for all (Matthews 1994, 1997; Giere 1999; Good and Shymansky 2001; Cobern and Loving 2003). I think with these authors that currently available perspectives on realism and rationalism are modern and accurate views of NOS that have enormous value to achieve a science education of quality.

Instructional proposals typically select topics from the nature of science on whose relevance for science education there is reasonable consensus amongst researchers, for instance: scientific method, theory change, realism, scientific explanation. The proposals infuse such topics into classroom activities using various strategies (for a broad range of strategies, see McComas 1998). For instance, a number of authors have turned to Giere's (1988) decisional model of scientific judgement in order to design nature-of-science activities for prospective and in-service science teachers (Duschl 1990; Jiménez Aleixandre 1996; Izquierdo 2000). These activities select and discuss famous episodes from the history of science.

In spite of the impressive base of proposals that has been thus generated, a weakness in the connection between theory and practice can be detected in many cases. Some instructional units employ content from the nature of science that can be considered outdated, or they combine contents from incompatible schools of thought. Another problem is a lack of reflection about the specific role of the nature of science in science teachers' professional induction.⋆ I have been developing, in previous publications (Adúriz-Bravo 2001b, c, 2002b; Adúriz-Bravo and Izquierdo, 2001; Adúriz-Bravo et al. 2001, 2002), some ideas that seek to provide criteria for a more theoretically founded *selection* of nature-of-science content. Such criteria should permit the adaptation of existing instructional procedures and also the development of new ones. Therefore, they could prove to be a powerful instructional tool both for science teachers and teacher educators.

This paper exemplifies the teaching of a few key elements from the nature of science selected through the use of this theoretical framework. The elements, bearing on scientific *method* and *values*, are infused into instructional activities by means of two historical episodes around the use of the pendulum, examined by Michael Matthews in his book *Time for Science Education* (Matthews 2000). Our selection of these two specific topics is supported by their appearance in many materials designed for NOS education of science teachers, but will be further justified below.

The first section of this paper identifies some available ideas to account for the need for a science teacher education that includes the nature of science as a central component. The second section makes a brief reference to my theoretical framework that could guide the inclusion of that component. I focus on one particular construct, the *strands* (i.e., structuring ideas) of the philosophy of science. The third section provides two examples of how episodes extracted from

---

⋆ Readers can refer to the proceedings of the very successful IHPST international conferences (e.g., Pavia 1999; Denver 2001; Winnipeg 2003) to spot instructional activities where the NOS topics to be taught are taken for granted without discussion, and where no specific theoretical basis for the *pedagogical* design is provided.

Matthews's work on the pendulum may be used for teaching the strands. I mainly profit from the 'Huygens section' of his book (Matthews 2000), later published independently (Matthews 2001). Finally, there is a short section that states some conclusive comments and future perspectives.

This paper is written with the intention of being a plausible example of the claim that theoretical reflection on the use of the nature of science in science teacher education permits both the *adaptation* of existing procedures (*evaluative* function) and the *creation* of new ones (*heuristic* function). In the instructional activities that I present, I take some available suggestions and further develop them along new directions. It is my hope that the ideas presented here can be of use and inspiration to other science teacher educators.

The Nature of Science in Science Teacher Education

A rapid review of the theoretical scenario related to science teacher education in the nature of science suggests that the available positions cover a broad spectrum. There is a small group of researchers who strongly object to an abusive use of the nature of science in compulsory education and therefore assume that this component has a restricted value when preparing science teachers. These researchers usually denounce the difficulties associated with the history of science in particular, stating that a heavily distorted 'pseudo-history' is often present in the secondary science curriculum (Brush 1974; Lombardi 1997; Fried 2001). Other authors contend that elements of the nature of science should be *implicit* in science education; there would be no need to contemplate specific instruction in the philosophy of science when designing the curriculum.

Among those frankly in favour of teaching the nature of science to science teachers, two main positions can be identified. One group concentrates on the intrinsic value that the nature of science has for the education of citizens; these authors resort to what Rosalind Driver and her colleagues label *democratic* and *cultural* arguments:

> An understanding of the nature of science is necessary if people are to make sense of socioscientific issues and participate in the decision-making process. (...) [It] is necessary in order to appreciate science as a major element of contemporary culture. (Driver et al. 1996, pp. 18–19)

Therefore, these authors argue that the nature of science needs to be introduced in science teacher education mainly because teachers are going to teach it in the classroom. I call this a *curriculum* perspective; it is well represented in the works of Hodson (1988) and Matthews (1994).

The other group looks rather at the participation of the nature of science in science teachers' professional development (Duschl 1990; Izquierdo 2000; Seroglou and Koumaras 2001), to a certain extent independently of curriculum considerations. The nature of science is assumed to represent a second-order reflection on the content and methods of science that positively contributes to teachers' autonomy in the task of *didactical transposition* (i.e., the decision-making when transforming scientists' science into school science). I call this a *meta-theoretical* perspective; my own proposals are in tune with this second perspective.

Along this latter line, one of the main points on which there is consensus is the idea of *functionality*. By this I mean a strong requirement that science teacher education in the nature of science must act as a *tangible* contribution to their own professional practice. That is, theoretical reflection on science is valuable in that it provides criteria and tools for science teachers to act in their classrooms (McComas 1998). Following this requirement, several constructs and activities have been diffused for public discussion.

I would like to argue that, although the enormous value of some of these available activities cannot be denied, some general directions are still lacking. According to many authors (Abimbola 1983; Gil-Pérez 1993; Izquierdo 2000; Leach 2001), science teacher education would require an explicit selection of some particular families of nature-of-science models. Choosing some models and rejecting others would ensure a *convergent* participation of this meta-theoretical component in teachers' thinking and practice. In my case, preference goes mainly towards the *cognitive model of science* (Giere 1988, 1999) and its counterpart in science education research (Izquierdo and Adúriz-Bravo 2003). I strongly adhere to Matthews's call for a rationalist and realist science curriculum; this conviction 'restricts' the diversity of epistemological and philosophical models at which I am looking when working with science teachers. Giere's account of the nature of science, and the ideas of the rest of authors that I claim it is worth examining with science teachers, fulfil this initial requirement.

In an attempt to achieve some degree of usefulness (or functionality, as defined above), I suggest that science teacher educators need an encompassing comprehension of the ideas on the nature of science that have been produced in academia, at least during last century. The constructs that I have developed are for the purpose of providing a *chart* of the available content and some criteria to prioritise and sequence it. The next section is devoted to one particular construct, which acts as a content *organiser* and inspires my pragmatic selection of two contributions by Matthews.

The 'Structuring Theoretical Fields' of the Philosophy of Science

My framework for teaching the nature of science to science teachers contains a number of elements that have been exposed in the previous publications mentioned above; in this sense, it is not my intention to repeat here material that readers have access to elsewhere. The core of the framework is related to a carefully guided *selection* of the content from the nature of science that can be taught to teachers once the role of this component in science teacher education is established and clarified. Selection is done by reviewing and articulating two key elements of twentieth-century philosophy of science – its major schools of thought and its main theoretical concepts.

I have proposed a coarse division of academic philosophy of science in three overlapping periods, which I call *stages*:

1. *Logical positivism and received view* (roughly covering from 1920 to 1965). This first stage sustains a strict, almost naïve, rationalist and realist reconstruction of science both as product and process. An initial division between the contexts of discovery and justification is respected. Formal logic and linguistics are extensively used. This stage is paradigmatically represented by the classical works of Carl Hempel (1966).
2. *Critical rationalism and the new philosophy of science* (approximately going from 1935 to 1980). This second stage represents a serious questioning of philosophical orthodoxy. Thomas Kuhn, Imre Lakatos and Stephen Toulmin are representatives of the 'irruption' of the history of science in the philosophy of science (Estany 1993); they defend the idea that a narrow internalism is theoretically insufficient.
3. *Postmodernism and contemporary accounts* (starting around 1970). Relevant authors representing postmodernism would be Larry Laudan and Paul Feyerabend, while Fred Suppe, Ulises Moulines and Ronald Giere, among a host of others, have produced what I rather broadly label 'contemporary' philosophical accounts. As I portray it, current philosophy of science comprises derivations and syntheses of both previous stages.

In parallel with this view of stages, I have put forward an abstract organisation of the stock of ideas on the nature of science, which I call the *structuring theoretical fields of the philosophy of science*, or more briefly *strands*. My design of this construct stems from a review of the literature in science education research that proposes a science curriculum development based on a few powerful pillar concepts, called 'structuring concepts' (Sanmartí and Izquierdo 1997). Accordingly, a 'structuring field' would be a set of interrelated concepts that give identity to a discipline. Some structuring concepts of physics would be 'energy' and 'interaction', while examples of structuring fields in the same discipline would be 'motion' or 'waves'.

I have been able to identify seven strands in twentieth-century philosophy of science, which roughly cover all the major theoretical concerns of this discipline produced by different schools of thought. Strands are labelled as follows:

1. *Correspondence and rationality.* This strand comprises two complementary aspects of the nature of scientific knowledge: the way in which it is believed that knowledge fits reality, and the criteria that scientists use in order to assess this fit.[2]
2. *Representation and languages.* This strand concerns the different structural units that philosophers of science have produced in order to account for the process of representation of the natural world (i.e., theories, models, laws, paradigms, ...). Abstract scientific entities are characterised by means of specialised language that is object of philosophical study.

3. *Intervention and method.* Approaches to the nature of science usually examine methodological matters pre-supposing various degrees of relationship between science and reality. 'Scientific method' is a construct that has generated strong debate among philosophers of science.
4. *Contexts and values*. This strand focuses on the relationships between science and the technological, socio-cultural and educational contexts, which are all characterised by their own aims and values.
5. *Evolution and judgement.* All models on the nature of science have included a diachronic component that provides assumptions on how science advances (Estany 1990).
6. *Demarcation and structure.* A philosophical issue as old as meta-theoretical reflection is that of distinguishing, or *demarcating*, between science and non-scientific intellectual enterprises.
7. *Normativity and recursion.* This last strand refers to the unique nature of the philosophy of science as a meta-scientific discipline, i.e., an academic discipline reflecting on science as a discourse and as an activity. Philosophers usually range from normative positions, in which *a priori* or absolutist parameters are sought, to a strong relativism.

Stages and strands permit us to *map* different theoretical models on the nature of science and to a certain extent assess their pertinence in science teacher education. In this sense, these constructs permit clearer options when selecting the nature-of-science elements to be taught. Both constructs work together in what I have called the *matrix of stages and strands* (Adúriz-Bravo and Izquierdo 2001). As they are 'orthogonal', they can be combined in a diachronic representation of the philosophy of science. The matrix thus obtained maps ideas, schools and authors placing them in a particular stage in time and in a particular thematic space (i.e., one or more strands).

My use of the matrix with science teachers can be exemplified with the topic of *scientific explanation*, which many NOS instructional proposals seek to teach. Figure 1 shows how we can trace three 'models of explanation', each one corresponding to a stage. Scientific explanation itself combines at least four strands, since it coalesces logical, linguistic, representational and methodological considerations and, at the same time, has been a nodal point in the task of demarcation.

This apparatus has allowed me to identify *scientific method* and *scientific values* as two interesting ideas for this paper (other key nature-of-science ideas are inspected in Adúriz-Bravo 2001c). I will show in the next section how I have designed specific instructional activities to teach these two ideas to prospective science teachers.

I follow earlier suggestions that contents of the nature of science can be successfully taught using central historical episodes as *case studies* (Irwin 2000; Matthews 2001). My source of materials from the history of science is Michael Matthews's extensive work on the role of the pendulum in Western culture.

Strands ↓	Stages →	Logical positivism & received view	Critical rationalism & new philosophy of science	Postmodernism & contemporary accounts
Correspondence & rationality		Explanation as a reasoning pattern (deductive logic) Hempel's covering-law model	Explanation as a text (pragmatics, rhetorics) Achinstein's illocutionary model	Explanation as modelling (analogies, abductive logic) Giere's model-based view
Representation & languages				
Intervention & method				
Demarcation & structure				

Figure 1. The 'matrix of stages and strands' permits tracing the evolution of meta-theoretical ideas on scientific explanation.

Practical Proposals Using Matthews's Work on the Pendulum

This section exemplifies two of the numerous and diverse instructional activities that can be constructed using material extracted from Matthews's (2000) book. The first activity is concerned with the use of formal logic in order to characterise algorithmic aspects of the scientific method, generally referred to as *scientific judgement*. A hypothetico-deductive model that regards theory testing as a *falsification* process is examined. The second activity examines the influence of contextual matters in science. Scientific progress is seen as a series of informed choices that take place within a scientific community holding a worldview and a set of values.

Rationales for including these two particular nature-of-science topics – method and context – in science teacher education have been extensively provided in NOS literature. It is easy to see how the methodological aspects of science matter in the international setting of new curricula that require students to answer, besides the usual scientific question 'what do we know?', the *epistemological* question, 'how have we come to know it?' (Duschl 1990; Osborne 1996). Scientific context and values have also been spotted as an important issue in science education; in this sense, the influence of Kuhn's inspiring ideas is enormous within our research community.

The activities that I present resort to well-known episodes spanning from seventeenth- to nineteenth-century history of science. These episodes are related to the European voyages of discovery and to the search of international standards for weights and measures. Both episodes can be connected to the life and works of the Dutch scientist Christiaan Huygens (1629–1695), who was one of the most active defenders of the use of the 'seconds pendulum' (i.e., a simple pendulum that swings at second intervals) as a universal standard of length.

I think that the Huygens section of *Time* (Matthews 2000, chapter 6, pp. 141–150) provides advantageous opportunities to address two of my strands: intervention/method and context/values. For the first strand, I select the key concept of scientific method and choose to teach it by analysing the advantages and limitations of a strictly logical account. To treat the second strand, the overall validity of *externalism* as a theoretical perspective on the nature of science is examined.

In relation to the scientific method, philosophers of science in the first half of last century favoured heavily rational reconstructions. Formal logic was extensively used within the so-called context of justification. Several versions of the method were put forward: an Aristotle-inspired inductive-deductive scheme, classical rationalist approaches following Newton and others, Popper's hypothetico-deductive falsificationism, and so on. The second half of last century saw the emergence of a more flexible view, acknowledging the existence of methodological diversity and identifying *modelling via abduction* as a key element. I suggest that Richer's voyage to Cayenne, as reported by Matthews, is an appropriate 'staging' to learn the distinction between the successive views on theory testing.

Regarding contextual factors, I adhere to a moderate externalism that is available in what I have called the third stage of the philosophy of science. The first stage completely disregarded the interference of social, cultural, economic and religious factors in scientific change. Authors from the second stage introduced as a great novelty a radical denial of this position (Estany 1990, 1993). But it can be argued that a *synthesis* of these two positions is more adequate for science teachers. The establishment of a metre that was accepted world-wide, as it is reconstructed by Matthews, is an excellent opportunity to reflect on these nature-of-science issues.

TEACHING THE STRAND OF INTERVENTION AND METHOD

Matthews briefly describes Jean Richer's trip to the French Guyana (South America), commissioned by the *Académie Royale des Sciences* in 1672–1673. One of the purposes of this trip was to confirm the invariability of the pendulum period with latitude (although the presence of a centrifugal effect due to Earth rotation had been predicted following Newton's framework, it was thought that this effect would prove too small to be detected). This assumed invariability came from the acceptance of the postulates of classical mechanics and the additional requirement of a perfectly spherical Earth.

Richer's negative results – he found that the seconds pendulum was shorter near the Equator – made it apparent that a revision of the apparatus underlying the study of pendulum motion and its use in time-keeping was needed. But several ways of doing this revision were suggested, attacking more or less deeply the theoretical core.

Under the label 'methodological matters' (p. 146 in the book), Matthews briefly exposes a standard process of falsification via a *modus tollens*, that is, a way of rejecting theories by means of a logical inference of a strict *deductive* nature. This scheme is best known through the work of Sir Karl Popper (1959). A theory T gives place through deduction to some predictions O that are 'observable'. According to classical formal logic, if these predictions are falsified (i.e., proved to be incorrect:

$\sim O$) when contrasted against experimental evidence, T needs to be rejected also ($\sim T$). The scheme would then be:

$$\begin{array}{l} T \rightarrow O \\ \sim O \\ \hline \sim T \end{array}$$

But this too direct account proves to be inapplicable in the Richer controversy. If the pendulum effectively changes its period, the source of the prediction O about invariability (that is, Newtonian mechanics T) is undermined. This overtly contradicts what happened in history.

A more elaborate version of the falsification process is obtained by means of the inclusion of a *ceteris paribus* clause C. This clause is implicitly attached to the deductive pattern and represents the hypothesis that ‘other things are equal’ when moving from theoretical predictions to experimental results. In the example with which we are dealing, C represents, among other things, the assumption of a spherical Earth. Within this new scheme, the premises of deduction include a *conjunction* between theory T and the clause C:

$$\begin{array}{l} (T.C) \rightarrow O \\ \sim O \\ \hline \sim T \mathrm{v} \neq \sim C \end{array}$$

The conclusion of this reasoning represents the choice between rejecting theory *or* C. In the Richer example, this latter option is of course more sensible and the oblate form of the Earth is eventually accepted.

Up till here, I have more or less described the activity suggested by Matthews, with my additional proviso that it needs to be adjusted and specified for the population of secondary science teachers (Matthews does not mention the target of his proposal in this section of the book). But there are still more elements that can be added to deepen this proposal inside the corresponding strand and introduce more recent accounts on the nature of the scientific method.

My own contribution to this proposal consists in going further into the use of patterns of logical inference. I suggest using compact representations of three different forms of inference: *deduction*, *induction* and *abduction*. I follow Charles Sanders Peirce’s canonical presentation of deductive, inductive and abductive argumentation patterns as permutations of the same three statements, alternatively functioning as premises and conclusions (Samaja 1994). It can be argued that a more complex account of the scientific method rises from the use of a refined version of what was traditionally named the *fallacy of the affirmation of the consequent*:

$T \to O$
O
....
T

From a strictly classical viewpoint, this form of method is flawed (and thus the dotted line represents a fallacious inference). Observations that confirm the prediction O do not add to the *truth* of T. But an abductive framework focussing on the ample analogical relationships between evidence and theoretical models avoids this difficulty and seems to provide a plausible reconstruction of scientists' cognitive and social functioning (Giere 1988; Samaja 1994).

One of the instructional activities that I have designed to discuss these ideas with science teachers uses Agatha Christie's *Death on the Nile* in book and film format (Adúriz-Bravo 2001a, 2002a). The detective story works as an analogue for scientific research, respecting its three key elements: problem, solution, and inferential connection between them. There is explicit comparison of two approaches to explanation (return to Figure 1), namely the one purported by philosophers of the received view and the one favoured by contemporary philosophers of science. The deductive-nomological model is mapped to Agatha Christie's construction of the plot: she *deduces* the clues knowing the murderer beforehand. The abductive-analogical model would correspond to detective Hercule Poirot's reconstruction of the crime: he *abduces* the identity of the murderer only knowing the clues.

Historical episodes – in connection with the evolution of atomic models – are provided to stage the rather abstract reflections generated during the activity. More concretely, the transition between Thomson's 'pudding model' and Rutherford's 'planetary model' for the atom is reconstructed as an abductive process. Working on Geiger's and Mardsen's well-known experiments of the gold-foil lamina, student teachers reconstruct Rutherford's inference. A mechanical analogue ('If small balls are thrown against a grid of knots and empty spaces, the balls can go through or bounce at variable angles') inspires the major premise:

If alpha particles are projected against a gold lamina constituted of small atomic nuclei and big empty spaces, the particles can go through or bounce at variable angles.
Some particles go through and some others (very few) bounce at variable angles.

The lamina is constituted of small atomic nuclei and big empty spaces.

TEACHING THE STRAND OF CONTEXT AND VALUES

I use Matthews's proposal once again in order to illustrate what is an *externalist* approach to the study of the nature of science, that is, one taking into account variables other than the internal logic of scientific knowledge. A strictly classical view on the processes of scientific change would minimise the relevance of socio-cultural forces in scientists' choices. On the other hand, a relativist – i.e., a 'second stage' – approach is excessively externally-driven and blurs epistemic considerations. I suggest turning to a synthetic view that attends to contexts and values and provides a more accurate picture of how scientific change takes place (Estany 1990).

Under the label 'political matters' (p. 147 in the book), Matthews narrates the debate concerning the French post-revolutionary decision for the establishment of an international standard of length. Huygens had proposed one hundred years before that the seconds pendulum could be used as a cheap and portable universal measure; a recovery of such proposal was considered and rejected by the *Commission des Poids et Mesures*. Instead, the committee approved and financed a determination of the length standard by means of a *geodetic* procedure – measuring the span of a ten-millionth part of the quadrant of arc of an Earth meridian. The length of the selected meridian, notably that going through Paris, was measured by Delambre and Méchain between 1792 and 1799, and after these measures the (in)famous brass 'metre' was cast.

This apparently irrational choice – the more expensive and time-consuming method is favoured because of somewhat obscure political matters – suggests that externalism is a sound theoretical idea for understanding the nature of science. But the same example can show that some amount of internalism needs to be conserved for a more accurate reconstruction of the episode, since

> Huygens' seconds pendulum length standard did survive its rejection by the academy. After years of patient measurement of the meridian sector, and the expenditure of a great deal of state money, the academy chose a fraction of the meridian distance that coincided with Huygens "three horological feet", and accepted the seconds pendulum as a secondary reference for its new length standard. (Matthews 2000, pp. 149–150)

The epistemic values of economy and simplicity are present in this survival, as well as the connections of Huygens's proposal to established physical theories. And Matthews suggests another internal element that can be usefully analysed by science teachers. The committee's rejection of Huygens's idea was partly founded on the argument that time and length considerations should not be mixed when establishing consensual space standards. Some two hundred years later, the shift to a length standard dependent on the *speed* of light would therefore represent an important epistemic breakpoint.

This proposal as stated by its original author can be expanded with the addition of more theoretical elements (theory load, incommensurability, conceptual change) and the translation to new historical contexts. Along the first line, I suggest the use of Giere's (1988) decisional model, which tries to strike an adequate balance between cognitive and social components in the scientific enterprise. On the other hand, in order to historically re-contextualise the discussion, the dispute between phlogiston- and oxygen-defenders in eighteenth-century chemistry provides the opportunity for a rich case study (Izquierdo 2000; Adúriz-Bravo 2001c).

Final Remarks

In the last twenty years or so, a vast number of practical proposals have become available world-wide to teach elements of the nature of science to prospective and in-service science teachers. Although these proposals are very valuable, most of them suffer from an absence of theoretical support. Marilar Jiménez Aleixandre (1996), for instance, has pointed to the fact that many NOS activities for teachers make use *exclusively* of the 'new philosophy of science' (i.e., philosophical developments from the 1960s), referring to this school as 'recent' or 'contemporary' NOS.

The strands are my proposal – still being refined and tested – to oppose this tendency and construct plausible examples for teacher education that give to science teachers professional autonomy in the field of the nature of science. The strands permit identifying very basic, *structuring*, ideas that should not be omitted in science teacher education.

One crucial question that remains unanswered in this paper is whether pre-service science teachers can benefit from my approach to NOS instruction.[3] I have not conducted so far any specific investigations to support an affirmative answer. As anecdotal data, I can comment that the application of these two activities on ten separate instances in three different countries suggests that the matrix of stages and strands is a powerful device to help teachers 'navigate' the philosophy of science, which to them represents a very complex and unknown discipline.

In relation to Michael Matthews's specific contribution centred around the pendulum, I am convinced that *Time for Science Education* contains an enormous number of ideas, suggestions and materials that deserve being further explored. One possible exploration can be done by means of the theoretical framework to which I have briefly referred in this paper. The two practical examples developed here are intended to constitute a proposal together with an opportunity for further developments.

Some slight imprecisions (cf. de Castro Moreira 2001) in the historical treatment of the Richer and metre episodes do not hinder their use in instructional sequences. I regard these two specific incidents suggested by Matthews as clear examples of his claim of the profound contribution which a study of pendulum motion can make to the science curriculum (Matthews 2000, p. 14).

Notes

[1] By 'temperate' realism and rationalism I refer to recent critical re-formulations of these long-standing philosophical positions; for instance, *perspectival realism* as depicted by Ronald Giere (1988, 1999) and *moderate rationalism* as proposed by Norwood Hanson (1958).

[2] Giere (1988) considers the ideas of *representation* and *judgement*, which closely correspond to this first strand, a major tool for discriminating between different philosophies of science.

[3] I am grateful to an anonymous reviewer of the paper who suggested the inclusion of this remark in the final version.

References

AAAS: 1989, *Science for All Americans. Project 2061*, Oxford University Press, New York.

Abimbola, I.O.: 1983, 'The Relevance of the "New" Philosophy of Science for the Science Curriculum', *School Science and Mathematics* **83**(3), 181–192.

Adúriz-Bravo, A.: 2001a, 'A Proposal to Teach the Abductive Argumentation Pattern Through Detective Novels', in D. Psillos (ed.), *Science Education Research in the Knowledge Based Society*, Aristotle University, Thessaloniki, volume II, pp. 715–717.

Adúriz-Bravo, A.: 2001b, 'A Theoretical Framework to Characterise and Assess Proposals to Teach the Philosophy of Science in the Context of Science Education', in R. Evans, A. Møller Andersen & H. Sorensen (eds.), *Bridging Research Methodology and Research Aims*, Danmarks Pædagogiske Universitet, Copenhagen, pp. 24–34.

Adúriz-Bravo, A.: 2001c, *Integración de la Epistemología en la Formación del Profesorado de Ciencias*, Universitat Autònoma de Barcelona, Bellaterra.

Adúriz-Bravo, A.: 2002a, 'Aprender sobre el Pensamiento Científico en el Aula de Ciencias: Una Propuesta para Usar Novelas Policiacas', *Alambique* **31**, 105–111.

Adúriz-Bravo, A.: 2002b, 'Un Modelo para Introducir la Naturaleza de la Ciencia en la Formación de los Profesores de Ciencias', *Pensamiento Educativo* **30**, 315–330.

Adúriz-Bravo, A. & Izquierdo, M.: 2001, 'Philosophy of Science in Science Teacher Education. Rationale and Practical Proposals', in *Proceedings of the 26th ATEE Annual Conference*, on line, http://www.lhs.se/atee/proceedings/bravo,_izquierdo_RDC_2.doc

Adúriz-Bravo, A., Izquierdo, M. & Estany, A.: 2001, 'A Characterisation of Practical Proposals to Teach the Philosophy of Science to Prospective Science Teachers', in N. Valanides (ed.), *Science and Technology Education: Preparing Future Citizens*, University of Cyprus, Paralimni, Volume I, pp. 37–47.

Adúriz-Bravo, A., Izquierdo, M. & Estany, A.: 2002, 'Una Propuesta para Estructurar la Enseñanza de la Filosofía de la Ciencia Para el Profesorado de Ciencias en Formación', *Enseñanza de las Ciencias* **20**(3), 465–476.

Brush, S.: 1974, 'Should the History of Science Be Rated X?', *Science* **183**, 1164–1172.

Cleminson, A.: 1990, 'Establishing an Epistemological Base for Science Teaching in the Light of Contemporary Notions of the Nature of Science and of How Children Learn Science', *Journal of Research in Science Teaching* **27**(5), 429–445.

Cobern, W. & Loving, C.: 2003, 'In Defense of Realism: It Really *Is* Commonsense', in W. McComas (ed.), *Proceedings of the Sixth IHPST Conference*, CD-ROM, IHPST Group, Denver, 031.

de Castro Moreira, I.: 2001, 'Comentário Sobre o Artigo *Metodologia e Política em Ciência: O Destino da Proposta de Huygens de 1673 Para Adoção do Pêndulo de Segundos Como un Padrão Internacional de Comprimento e Algumas Sugestões Educacionais*, de Michael Matthews', *Caderno Catarinense de Ensino de Física* **19**(1), electronic version.

Driver, R., Leach, J., Millar, R. & Scott, P.: 1996, *Young People's Images of Science*, Open University Press, Buckingham.

Duschl, R.: 1990, *Restructuring Science Education. The Importance of Theories and Their Development*, Teachers College Press, New York.

Estany, A.: 1990, *Modelos de Cambio Científico*, Crítica, Barcelona.

Estany, A.: 1993, *Introducción a la Filosofía de la Ciencia*, Crítica, Barcelona.

Fried, M.: 2001, ‘Can Mathematics Education and History of Mathematics Coexist?’, *Science & Education* **10**(4), 391–408.

Giere, R.: 1988, *Explaining Science. A Cognitive Approach*, University of Minnesota Press, Minneapolis.

Giere, R.: 1999, ‘Del Realismo Constructivo al Realismo Perspectivo’, *Enseñanza de las Ciencias*, extra issue, 9–13.

Gil-Pérez, D.: 1993, ‘Contribución de la Historia y de la Filosofía de las Ciencias al Desarrollo de un Modelo de Enseñanza/Aprendizaje como Investigación’, *Enseñanza de las Ciencias* **12**(2), 154–164.

Good, R. & Shymansky, J.: 2001, ‘Nature-of-Science Literacy in Benchmarks and Standards: Post-Modern/Relativist or Modern/Realist?’, *Science & Education* **10**(1&2), 173–185.

Hanson, N.R.: 1958, *Patterns of Discovery: An Inquiry Into the Conceptual Foundations of Science*, Cambridge University Press, Cambridge.

Hempel, C.: 1966, *The Philosophy of Natural Science*, Prentice Hall, Englewood Cliffs.

Hodson, D.: 1988, ‘Toward a Philosophically More Valid Science Curriculum’, *Science Education* **72**(1), 19–40.

Irwin, A.: 2000, ‘Historical Case Studies: Teaching the Nature of Science in Context’, *Science Education* **84**(1), 5–26.

Izquierdo, M.: 2000, ‘Fundamentos Epistemológicos’, in F.J. Perales and P. Cañal (eds.), *Didáctica de las Ciencias Experimentales. Teoría y Práctica de la Enseñanza de las Ciencias*, Marfil, Alcoy, pp. 35–64.

Izquierdo, M. & Adúriz-Bravo, A.: 2003, ‘Epistemological Foundations of School Science’, *Science & Education* **12**(1), 27–43.

Jiménez Aleixandre, M.P.: 1996, *Dubidar para Aprender*, Ediciôns Xerâis, Vigo.

Leach, J.: 2001, ‘Epistemological Perspectives in Science Education Research’, in D. Psillos (ed.), *Science Education Research in the Knowledge Based Society*, Aristotle University, Thessaloniki, volume I, pp. 13–15.

Lombardi, O.: 1997, ‘La Pertinencia de la Historia en la Enseñanza de Ciencias: Argumentos y Contraargumentos’, *Enseñanza de las Ciencias* **15**(3), 343–349.

Matthews, M. (ed.): 1991, *History, Philosophy and Science Teaching: Selected Readings*, OISE Press, Toronto.

Matthews, M.: 1994, *Science Teaching: The Role of History and Philosophy of Science*, Routledge, New York.

Matthews, M.: 1997, ‘James T. Robinson’s Account of the Philosophy of Science and Science Teaching: Some Lessons for Today from the 1960s’, *Science Education* **81**(3), 295–315.

Matthews, M.: 2000, *Time for Science Education: How Teaching the History and Philosophy of Pendulum Motion can Contribute to Science Literacy*, Plenum Publishers, New York.

Matthews, M.: 2001, ‘Methodology and Politics in Science: The Fate of Huygens’ 1673 Proposal of the Seconds Pendulum as an International Standard of Length and Some Educational Suggestions’, *Science & Education* **10**(1&2), 119–135.

McComas, W. (ed.): 1998, *The Nature of Science in Science Education. Rationales and Strategies*, Kluwer, Dordrecht.

Mellado, V. & Carracedo, D.: 1993, ‘Contribuciones de la Filosofía de la Ciencia a la Didáctica de las Ciencias’, *Enseñanza de las Ciencias* **11**(3), 331–339.

Millar, R. & Osborne, J.: 1998, *Beyond 2000: Science Education for the Future*, King’s College, London.

NRC (National Research Council): 1996, *National Science Education Standards*, National Academy Press, Washington.

Nussbaum, J.: 1983, ‘Classroom Conceptual Change: The Lessons to be Learned from the History of Science’, in H. Helm & J. Novak (eds.), *Misconceptions in Science and Mathematics*, Cornell University, Ithaca.

Osborne, J.: 1996, ‘Beyond Constructivism’, *Science Education* **80**(1), 53–82.

Popper, K.: 1959, *The Logic of Scientific Discovery*, Basic Books, New York (German original edition of 1934).

Samaja, J.: 1994, *Epistemología y Metodología. Elementos Para una Teoría de la Investigación Científica*, Eudeba, Buenos Aires.

Sanmartí, N. & Izquierdo, M.: 1997, ‘Reflexiones en Torno a un Modelo de Ciencia Escolar’, *Investigación en la Escuela* **32**, 51–62.

Seroglou, F. & Koumaras, P.: 2001, ‘The Contribution of the History of Physics in Physics Education: A Review’, *Science & Education* **10**(1&2), 153–172.