

A proposal to teach the nature of science (NOS) to science teachers: The ‘structuring theoretical fields’ of NOS

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ABSTRACT

This article sketches a theoretical framework that I have been devising in order to teach the nature of science (NOS) to pre- and in-service science teachers for all the educational levels (from kindergarten to university). The framework suggests that teachers should learn a set of simple ‘key-ideas’ from NOS. Those key-ideas can be selected and validated through a matrix that has two ‘structuring’ components: 1. a list of the main schools of twentieth-century philosophy of science (called stages); and 2. a list of their main fields of inquiry (called strands). Examples of NOS contents within and across some of the three stages and seven strands that I have identified, together with suitable pedagogies, are presented here under the form of three didactical units.

KEY WORDS

Nature of science, teacher education, key-ideas, matrix of stages and strands, didactical units.

RÉSUMÉ

Cet article présente un cadre théorique que j’ai conçu pour enseigner la nature de la science (NOS) aux professeurs de science en formation et en activité pour tous

les niveaux éducatifs (du kindegarten à l'université). Ce cadre suggère que les professeurs devraient apprendre un ensemble d'«idées-clefs» simples de NOS. Cette idées-clefs peuvent être sélectionnées et validées au moyen d'une matrice qui a deux composants «structurants»: 1. une liste des écoles principales de la philosophie des sciences du XXème siècle (appelées étapes); et 2. une liste de ses champs principaux d'investigation (appelés champs théoriques structurants). Je présente ici –sous forme d'unités didactiques– des exemples de contenus de NOS dans et à travers quelques-uns des trois étapes et des sept champs que j'ai identifiés; les contenus sont accompagnés de méthodologies d'enseignement appropriées.

MOTS-CLÉS

Nature de la science, formation des professeurs, idées-clefs, matrice d'étapes et champs, unités didactiques.

NOS AS A RESEARCH FOCUS IN DIDACTICS OF SCIENCE

The philosophy, history, sociology, psychology and linguistics of science are sometimes called *meta-sciences*, using the Greek prefix 'metà' with the meaning 'beyond', since they constitute second-order reflections *on* science as a product and as a process (Estany, 1993). In this sense, *didactics of science* (i.e. science education as a discipline) can also be considered meta-scientific in part (Adúriz-Bravo, 2001c).

The importance of meta-sciences for science education has been acknowledged by educational researchers, policy makers and science teachers (AAAS, 1989; Matthews, 1994; Driver et al., 1996; NRC, 1996; Millar & Osborne, 1998). Accordingly, rationales and proposals have been put forward in the last twenty-five years with the aim of teaching conceptualisations on the *nature of science* to different audiences (Duschl, 1990; Matthews, 1991, 2000; Jiménez Aleixandre, 1996; McComas, 1998; Flick & Lederman, 2004; Adúriz-Bravo, 2005a).

The available theoretical developments within this research line, known by the very same name of its object of study –*nature of science*–, or more commonly by its English acronym NOS, generally point to the need to identify *epistemological foundations* that are both *valuable* and *useful* for science education (Izquierdo & Adúriz-Bravo, 2003). 'Valuable' in the sense that such foundations constitute a relevant curriculum component to attain the aims of genuine *scientific literacy*, and 'useful' in the sense that they represent an efficient tool in science teacher professional development.

Authors within the research line of NOS usually establish connections between well-known views from the philosophy of science (e.g. hypothetico-deductivism, revo-

lutionism, constructivism, axiology) and models of science teaching (e.g. Nussbaum, 1983; Cleminson, 1990; Mellado & Carracedo, 1993; Izquierdo & 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 (Matthews, 1994, 2000; Giere, 1999; Good & Shymansky, 2001; Cobern & Loving, 2003) have advocated the urgent need to recover *temperate* versions of realism and rationalism (Hanson, 1958), which are more compatible than relativist philosophies with the aims of 'liberal' science education. I think with these authors that currently available perspectives on realism and rationalism are NOS views that have great potential to achieve a *science education of quality for all* (Adúriz-Bravo, 2005a).

Didactical proposals typically select topics from NOS on whose relevance for science education there is reasonable consensus amongst researchers and teachers, for instance: scientific method, theory change, realism, scientific explanation, theory-ladenness of observation. Proposals then 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) model of scientific method in order to design NOS activities for prospective and in-service science teachers (Duschl, 1990; Jiménez Aleixandre, 1996; Izquierdo, 2000; Adúriz-Bravo, 2005a, 2005b). These activities select and discuss famous episodes from the history of science (Galileo's 'installation' of the experimental method; the initial rejection of continental drift as a far too problematic hypothesis; the 'race' for the structure of DNA between groups of various backgrounds; Fleming's fortunate blunder leading to the 'discovery' of penicillin...).

In spite of the undoubtedly impressive pool of NOS proposals that has been thus generated, a weakness in the connection between theory and practice is still detected in some cases. Some materials employ, without further discussion, NOS content that can be considered outdated (e.g. logical positivism), or they combine ideas from incompatible schools of thought (e.g. Popper and Kuhn). Another problem is a lack of reflection about the specific role of NOS in science teachers' professional induction. I have been developing, in previous publications (Adúriz-Bravo 2001b, 2001c, 2002b; Adúriz-Bravo & Izquierdo, 2001; Adúriz-Bravo et al., 2001, 2002), some ideas that seek to provide criteria for a more theoretically founded *selection* and *organisation* of NOS content to be taught. Such *structuring* criteria should permit the adaptation of existing didactical procedures (i.e. *pedagogies*) and also the development of new ones. Therefore, they could prove to be a powerful didactical tool both for science teachers and for science teacher educators.

This paper exemplifies the teaching of a few elements from NOS selected and shaped through the use of my theoretical framework. These elements assume the form of what we can call *key-ideas* of NOS, that is, simple statements on what science is,

how it changes in time, and how it relates to society and culture (Adúriz-Bravo, 2005a). My selection of specific NOS topics that can be considered *educationally* worthwhile is supported by their appearance in many materials designed for NOS education of science students and teachers, but will be further discussed below.

The first section of this paper spots available arguments that support the need for a science teacher education including NOS as a central component. The second section makes reference to my theoretical framework that could guide the inclusion of such NOS component. I focus on one particular construct, the *strands* (technically, the *structuring theoretical fields*) of NOS, which could be considered thematic ‘throughlines’ that traverse meta-scientific reflection, generating problems that are then tackled in specific ways by the different schools of thought. The third section provides some examples of how episodes from the history of science can serve as a ‘set’ (in the sense in which this term is used in cinema) to teach key-ideas. Such ideas show how some questions from the strands were in fact *answered* by particular NOS schools, authors, texts and constructs. Finally, there is a short section that states some conclusive comments.

My claim in this paper is that *didactical* reflection on the use of NOS in science teacher education permits both the *adaptation* of existing protocols (*evaluative* function) and the *creation* of new ones (*heuristic* function) in order to teach a more contextualised, *epistemologically informed* science in the classrooms.

NOS AND SCIENCE TEACHER EDUCATION

A quick review of the theoretical scenario related to the introduction of NOS in science teacher education suggests that there are stances covering a broad spectrum; in this sense, further debate is still needed within the community of didactics of science. There is a small group of researchers and teachers who object to an abusive use of NOS in compulsory education and therefore assume that this component has restricted value when educating science teachers. These researchers and teachers usually denounce the difficulties associated with the history of science in particular, stating that a heavily distorted ‘pseudo-history’, which serves no clear educational purpose, is often present in the secondary science curriculum (Brush, 1974; Lombardi, 1997; Fried, 2001). Other authors contend that elements of NOS should be *implicit* in science education; there would be no need to contemplate specific instruction when designing the curriculum: students –and teachers– would learn NOS just by *doing science*.

Among those in favour of teaching NOS to science teachers, two main positions can be identified. One group concentrates on the intrinsic value that NOS has for the education of citizens (i.e. critical, autonomous, tolerant individuals who can live in society); these authors resort to what Rosalind Driver and her colleagues, in a text that is now classic, 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, p. 18-19).

Therefore, supporters of this position argue that NOS would need 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 work of scholars within the English-speaking tradition, such as Derek Hodson (1988) and Michael Matthews (1994).

The other group focuses on the participation of NOS in science teachers’ *professional development* (Duschl, 1990; Izquierdo, 2000; Seroglou & Koumaras, 2001; Adúriz-Bravo, 2006; Niaz, 2006) to a certain extent *independently* of curriculum considerations. NOS is then 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*.

One of the main points on which there is consensus in NOS research is the idea of *functionality*. By this I mean a strong requirement that science teacher education in NOS must act as a *tangible* contribution to their own practice. That is, theoretical reflection on science is valuable in that it provides criteria and tools for science teachers to act in their own classrooms (McComas, 1998; Flick & Lederman, 2004; Adúriz-Bravo, 2005a). Following this requirement, several ideas and activities have been diffused for public discussion within the community of didactics of science.

I would like to argue that, although the enormous value of this available corpus 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 NOS models, selected in terms of their educational value. 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 & Adúriz-Bravo, 2003). I strongly adhere to Michael Matthews’s (1994, 2000) call for a moderately rationalist and realist science curriculum; this conviction ‘restricts’ the diversity of philosophical models at which I am looking when working with science teachers. Giere’s account of NOS, 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 functionality (as it was defined above) in science teacher education, I suggest that teacher educators need an encompassing comprehension of the NOS ideas that have been produced during the 20th century.

The constructs that I have developed aim at providing a *chart* of the available content and some criteria to prioritise key-ideas and put them into a sequence (Adúriz-Bravo, 2001b, 2001c). The next section is devoted to one particular construct, which acts as a content *organiser*.

THE “STRUCTURING THEORETICAL FIELDS” OF NOS

My framework for teaching NOS to science teachers contains a number of ideas that have been diffused in the previous publications mentioned above; in this sense, it is not my intention to review here materials that readers can access elsewhere (in Spanish and in English). The core of the framework is related to a carefully guided *selection* of the content from NOS that can be taught to teachers once the role of this component in science teacher education has been established. Selection is done by reviewing and articulating two *core* elements of 20th century philosophy of science – its major schools of thought and its main theoretical concerns, or lines of inquiry.

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 rationalist and realist reconstruction of science both as product and as process. An initial division between the contexts of discovery and justification is respected, and logic and linguistics are extensively used to account for the latter. 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 undermining 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 when describing theory change and scientists’ judgement.
3. *Postmodernism and contemporary accounts* (starting around 1970). Relevant authors representing postmodernism within philosophy of science would be Paul Feyerabend and, to a lesser extent, Larry Laudan and Willard van Orman Quine, while Fred Suppe, Ulises Moulines, Nancy Cartwright and Ronald Giere, among a host of others, have produced what I rather broadly label ‘contemporary’ philosophical contributions to NOS. As I portray it, current philosophy of science comprises derivations, refinements and syntheses of the two previous stages, while NOS combines this ‘emerging’ philosophical constructions with elements from other meta-sciences (especially from the sociology of science, cognitive science, and science studies).

In parallel with this view of stages, I have put forward an abstract organisation of the

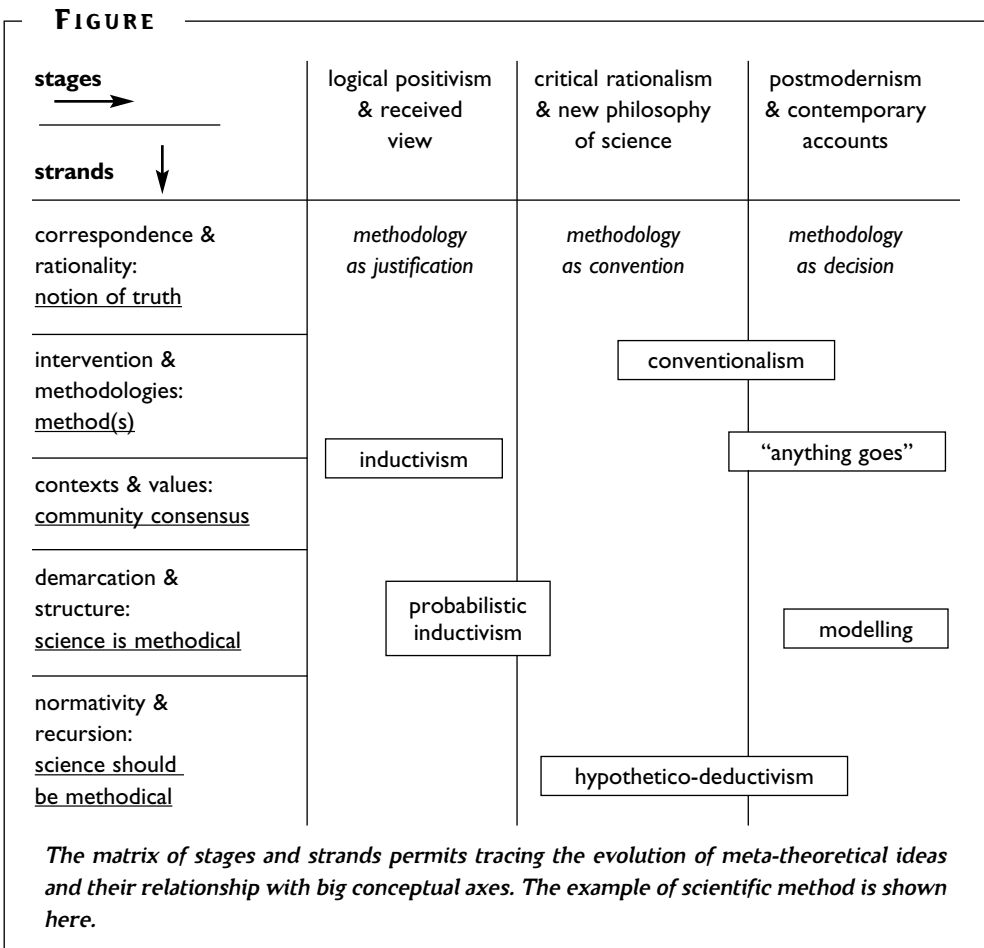
pool of ideas on the nature of the scientific enterprise, which I call the *structuring theoretical fields of NOS*, or more briefly *strands*. My design of this construct stems from a review of the literature within didactics of science that proposes a science curriculum development based on a few powerful pillar concepts, called ‘structuring concepts’ (Sanmartí & Izquierdo, 1997). Accordingly, a ‘structuring field’ would be a set of inter-related concepts that give *identity* to a discipline. Some structuring concepts of physics would be ‘energy’, ‘interaction’ and ‘potential’, while examples of structuring fields in the same discipline would be ‘motion’, ‘electricity’ or ‘waves’.

Through a revision of the literature concerned with the teaching of the philosophy of science (i.e. introductory manuals for undergraduates), I have been able to identify seven strands in NOS, which would roughly cover all the major philosophical concerns on science produced by different research traditions. Strands are labelled as follows:

1. *Correspondence and rationality*. This first strand comprises two complementary aspects of the nature of scientific knowledge: the way in which it is believed that knowledge ‘fits’ the world (i.e. how what we say corresponds to reality), and the criteria that scientists use in order to assess the validity of such a fit.
2. *Representation and languages*. This second strand is concerned with the different *units of analysis* 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 highly specialised multi-semiotic languages that can be the object of philosophical study.
3. *Intervention and methodologies*. Science is usually studied examining methodological matters, assuming various degrees of relationship between the scientist and its object. ‘Scientific method’ is a construct that has generated strong debate among philosophers of science and, at the same time, functions as an idea that teachers find useful in science education.
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, intentions and values (Echeverría, 1998). Scientific communities have also been inspected within this strand.
5. *Evolution and judgement*. Almost all models on how science works have included a diachronic component that provides assumptions on the ways in which scientific knowledge advances and increases (Estany, 1990). This strand discusses the very notion of scientific *progress*.
6. *Demarcation and structure*. A philosophical issue as old as meta-theoretical reflection is that of distinguishing, or –in Popper’s words– *demarcating*, between science and non-scientific intellectual enterprises. In this latter space, many different human activities are included: from ‘disciplined’ efforts (technologies, arts, humanities...) to *pseudo-science* as an intellectual imposture.

7. *Normativity and recursion.* This last strand refers to the unique nature of the philosophy of science as the meta-scientific discipline *par excellence*, i.e. an academic discipline, of scientific character, reflecting on science as a discourse and as an activity. Philosophers usually range from very normative positions, in which *a priori* or absolutist parameters to direct science are sought, to a strong relativism (Feyerabend’s ‘anything goes’). The *naturalisation* of the philosophy of science after Quine seems to be a ‘third way’ in this debate.

Stages and strands permit to *map* different theoretical models on science and at the same time assess their pertinence in science teacher education. In this sense, these constructs permit clearer options when selecting NOS elements that should be taught. Both constructs work together in what I have called the *matrix of stages and strands*



(Adúriz-Bravo & Izquierdo, 2001). As they are ‘orthogonal’, they can be combined in a diachronic representation of the philosophy of science (at least since it became *professionalised* with the Vienna Circle). The matrix thus obtained arranges 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 this device with science teachers can be exemplified with the topic of *scientific method*, which many NOS instructional proposals seek to teach (cf. Duschl, 1990; McComas, 1998; Flick & Lederman, 2004). Figure 1 shows how we can trace many ‘models of method’, corresponding to sharp stages or to the transitions between them. Scientific method as a ‘theme’ combines many strands, since it coalesces logical, representational, methodological, social, decisional, axiological and normative considerations. At the same time, method has been a classical Ockham’s razor in the task of demarcation: science was usually defined as the activity *following* the scientific method.

The theoretical apparatus that I have briefly described here has allowed me to identify central NOS ideas for science teacher education (Adúriz-Bravo, 2001c, 2005a, 2005b, 2006). I will show in the next section how I have designed specific didactical units to teach those key-ideas to science teachers. My units follow earlier research-based suggestions that NOS contents can be successfully taught using *memorable* episodes from the history of science in the format of *case studies* (Duschl, 1990; Irwin, 2000; Matthews, 2000; Seroglou & Koumaras, 2001).

DIDACTICAL PROPOSALS TO TEACH NOS TO SCIENCE TEACHERS

This section exemplifies three self-contained sets of teaching activities (i.e. didactical units) that I have constructed to acquaint prospective teachers with relevant aspects of NOS. The first unit revolves around the construct of *image of a scientist*. It aims at discussing the ways in which lay people see scientists ranging from scientific heroes to unknown science workers. Issues of social importance such as *scientism*, elitism and sexism are discussed.

The second activity uses introductory logic in order to characterise decisional aspects within the scientific method, a topic generally referred to as *scientific judgement*. Some of the methodological models of figure 1 are critically compared through their relative value in rationally reconstructing the same episodes of scientific discovery.

The third activity examines the relations between creator and creation in science, and the responsibilities entailed by the scientific enterprise, in the light of a network of socially shared values. Socioscientific issues are reviewed through the lens of appropriate axiological constructs.

Rationales for including these three particular NOS topics in undergraduate science teacher education have been repeatedly provided in the available literature:

1. The scientific image is connected to what is known as *public understanding of science*; in this sense, a genuine science education of quality for all cannot avoid tackling the problem of the democratisation of science as human heritage (Driver et al., 1996; Acevedo Díaz, 2004).
2. It is easy to see how methodological aspects of science matter in the international scenario of new curricula requiring 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).
3. Values in science are also a matter of concern among teachers and researchers. In our current *technocratic* society, science education proposes the ambitious aim of forming critical people who can understand the social, political, economic, cultural, religious, military and ideological underpinnings of science.

Teaching key-ideas on the nature of scientific actors

This first didactical unit proposes working on the very diverse –sometimes even incompatible– *images* of Marie Curie that have been constructed in scientific, historical and popular literature and visual arts. Student teachers compare the ‘hagiographic’ view generated by Marie’s daughter Ève Curie in the 30s with a broad selection of more recent –and far more refreshing– approaches to the figure, including the French commercial film *Les palmes de Monsieur Schutz* (released in 1997), Sánchez Ron’s (2000) magnificent biography, and an episode from *The Simpsons* featuring oversized, radioactive Curies devastating Tokyo.

With these materials, we enter into a debate around the role of women in science and the problem of the individual scientist versus the scientific community. The unit concentrates on the *contexts* and *values* involved in scientific research (my strand 4), specifically regarding the figure of Madame Curie as an *epitome* of women in science. Maria Skłodowska is undoubtedly one of the most visited figures from the history of science; several images and icons have been constructed at her expense. Such extensive treatment provides a fertile arena for science teachers to examine *science-in-the-making* as seen by scientists themselves and by the general public.

We provide here for the readers an example of the kind of *kitsch*, pseudo-historical reconstruction that our student teachers discuss and contest during the activities: “Yes, these four heroic years were, not the happiest of Marie Curie’s life, but the most perfect in her eyes, the nearest to those summits of the human mission toward which her gaze had been trained. When one is young and solitary and swallowed up in study, one can ‘not have enough to live on’ –and yet live to the fullest. An immense enthusiasm gave this girl of twenty-six the power to ignore the trials and privations she endured, to magnify her sordid

existence into magic. Later on, love, maternity, the worries of a wife and mother, the complexities of crushingly hard work, were to restore the visionary to real life. But in the enchanted moment when she was poorer than she was ever to be again, she was as reckless as a child. She floated lightly in another world, that which her thought was to regard always as the only pure and true one” (Curie, 1940, p. 117).

Teaching key-ideas on the nature of scientific method

This second didactical unit discusses possible reconstructions of the logic underneath methodology using Agatha Christie’s mystery novel *Death on the Nile* and the film created upon it (Adúriz-Bravo, 2001a, 2002a, 2005b). The detective story works as an analogue for scientific research, respecting its three key elements: problem, solution, and the inferential connection between them. There is explicit comparison of several philosophical approaches to method (cf. Figure). A hypothetico-deductive model is mapped to Agatha Christie’s construction of the plot: she *deduces* the clues knowing the murderer beforehand. An analogical-abductive model would correspond to detective Hercule Poirot’s reconstruction of the crime: he *abduces* the identity of the murderer from the clues that he has collected and selected.

The standard methodological procedure according to Sir Karl Popper (1959) is that of falsification via a *modus tollens*, that is, rejecting theories by means of a logical inference of a strict *deductive* nature. A theory T gives place through deduction to some ‘observable’ predictions O. According to 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 schema would then be:

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

But this too direct account proves to be inapplicable in many cases, as suggested by Hungarian-born philosopher Imre Lakatos (1970). Naïve falsificationism overtly contradicts what usually happens in the history of science.

A more elaborate version of the falsification process is obtained by means of the inclusion of a *ceteris paribus* clause C. This clause, attached to the deductive pattern, represents the hypothesis that ‘other things stay equal’ when moving from theoretical predictions to experimental results. Within this new schema, premises of deduction include a *conjunction* between theory T and the clause C:

$$\begin{array}{c}
 (T \cdot C) \rightarrow O \\
 \sim O \\
 \hline
 \sim T \vee \sim C
 \end{array}$$

The conclusion of this reasoning pattern represents the choice between rejecting the whole theory or just C.

Still more elements are added to deepen this picture inside the corresponding strands (especially strand 3) and to introduce more recent accounts on the nature of scientific methods. We go further into the use of patterns of logical inference, using compact representations of three different forms of inference: *deduction*, *induction* and *abduction* (or ‘inference to the best explanation’). To do this, I propose following Charles Sanders Peirce’s canonical presentation of deductive, inductive and abductive argumentations 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*:

$$\begin{array}{c}
 T \rightarrow O \\
 O \\
 \hline
 T
 \end{array}$$

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 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).

In the unit, historical episodes –for instance, in connection with the evolution of *atomic models*– are provided to stage these rather abstract reflections. 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 propose different interpretations of Rutherford’s construction.

Teaching key-ideas on the nature of scientific values

This last didactical unit intends to illustrate what has been known –in the philosophy of science– as an *externalist* approach, by applying it to the study of the nature of scientific innovation. The generation of novelty in science is examined 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 sociocultural influences in scientists’ actions. On the other hand, a relativist –i.e. a ‘second stage’– approach is excessively externally-driven and blurs epistemic considerations. This unit suggests turning to a ‘synthetic’, ‘third stage’, view that provides a more accurate picture of how scientific changes take place (Estany, 1990).

In order to historically contextualise such a discussion, several famous episodes are used. The dispute between phlogiston- and oxygen-defenders in eighteenth-century chemistry (Izquierdo, 2000; Adúriz-Bravo, 2001c, 2005a), for instance, provides the opportunity for a rich case study in which the idea of creating can be discussed. The unit thus moves to the consideration of the complex relations between creator and creation, using the classical Greek concept of *demiurgy*. Doing science is seen through the lens of human creation as reconstructed in myth and poetry: Adam, the Golem, Frankenstein’s creature, Pinocchio, the *Doppelgänger*, and the replicants in *Blade Runner* are but a few of the numerous examples addressed with teachers (Adúriz-Bravo, 2005b; Seroglou & Adúriz-Bravo, 2007).

An axiological perspective (from strand 4, dealing with ethical codes in science, and from strand 7, related to the normative aspects of meta-scientific discourse) is finally used to discuss the *responsibility* of scientists at work. Several socioscientific issues (cloning, eugenics, euthanasia...) serve the purpose of anchoring the discussion in concrete instances where the reach and limits of science is at stake.

CONCLUSIVE REMARKS

In the last two or three decades, a vast number of practical proposals have become available world-wide to teach NOS elements to prospective and in-service science teachers. Although these proposals are very valuable, most of them suffer from some degree of 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 1950s and 60s, my second stage), abusively referring to this school as ‘recent’ or ‘contemporary’ NOS.

The structuring theoretical fields of NOS are my proposal –still being refined and assessed– to oppose this tendency and construct plausible examples to give to science teachers professional autonomy in the realm of NOS, in which they are currently required to be *competent*. On the one hand, strands permit them to identify very basic,

structuring, ideas that should not be omitted in science education in all educational levels, responding in this way to the curriculum perspective in teacher training. On the other hand, strands provide powerful theoretical models for teachers to inspect their own teaching object, thus tuning with the meta-scientific perspective.

One central question that remains unanswered in this paper is to what extent pre- and in-service science teachers benefit from my approach to their NOS education, based on the learning of key-ideas. I have not conducted so far specific investigations to support an answer showing conceptual and practical *changes*. As anecdotal data, I can comment that the application of my ideas and units on at least twenty separate instances in eight different countries (covering more than 3000 teachers so far) suggests that the matrix of stages and strands is an engaging device that helps teachers 'navigate' NOS, which to them represents a very complex and unknown component of the science curriculum.

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