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ABSTRACT

The philosophy of science is considered one of the important elements in the transformation of science education into the 21st century. This paper focuses on the integration of the philosophy of science into science teacher education by analyzing the theoretical framework of three didactical units. The first unit aims to teach a set of central concepts from a 20th century philosophy of science by using the detective novel Agatha Christie's "Death on the Nile." The second didactic unit illustrates the relationship between science, technology, and society which was developed by Michael Matthews. The third unit focuses on the context of values, evolution, and judgment. (Contains 34 references.) (YDS)

A Characterisation of Practical Proposals to Teach the Philosophy of Science to Prospective Science Teachers

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INTRODUCTION

The philosophy of science has been recognised by recent scholarship as a key contribution to the transformation of science education for the twenty–first century, in accordance with the new and ambitious aims that have been proclaimed for democratic scientific literacy in many countries (Duschl, 1990; Driver et al., 1996; McComas and Olson, 1998; Millar and Osborne, 1998). The philosophy of science may be of great help in achieving the goals that have been put forward for the preparation of future citizens, due to its critical nature and its power to inform public understanding of techno-scientific issues involving complex political, economic, environmental and ethical components (McComas et al., 1998; Monk and Osborne, 1997). This is an important consideration in the current panorama, in which science pervades every aspect of everyday life but, at the same time, faces strong attacks from antiscientific scholarship, such as the so–called sociology of scientific knowledge (Matthews, 1998).

With this general background, the need for the introduction of the metasciences (the philosophy, history and sociology of science) in the school science curriculum and in science teacher education has been repeatedly advocated in the literature of didactics of science during the last fifteen years (Duschl, 1990; Matthews, 1994, 1998; McComas, 1998). Metascientific contents are recognised as a fundamental component of the contemporary ideal of scientific literacy (Millar, 1989; Monk and Osborne, 1997); this component has been labelled the *nature of science* (McComas, 1998) or ideas–about–science (Millar and Osborne, 1998). Thus, there is consensus that it is necessary for the educated citizen of the twenty–first century not only to know science but also to know *about* science: how it is created, how it evolves through history, and how it relates to society and culture. As the report *Beyond 2000* puts it,

> young people need an understanding of how scientific inquiry is conducted – to help them appreciate the reasoning which underpins scientific knowledge claims, so that they are better able to appreciate both the strengths and the limitations of such claims, in a range of situations and contexts. (Millar and Osborne, 1998: 11–12)

Apart from this intrinsic value, contents from the philosophy of science have long been considered as a powerful auxiliary tool for the teaching and learning of science. That is, *instrumental* aims have also been advocated for the philosophy of science in science education. According to this, several topics from the philosophy of science have been introduced in the science curriculum and in science teacher education. On the other hand, the philosophy of science is considered a strategic field within science teachers' professional knowledge (Bromme and Tillema, 1995), influencing other fields, such as their ideas on teaching and learning science. Hence the interest of didactics of science to conduct research on teachers' ideas on the nature of science and to issue proposals to improve them (Lederman, 1992; McComas, 1998). The philosophy of science may be of great help for science teachers who face the challenge of preparing future citizens.

Taken this into account, we have focused on the examination of available proposals regarding the integration of the philosophy of science in science teacher education. We have dealt with this integration by means of a theoretical framework that has allowed us to assess the available proposals (Adúriz–Bravo, in press–b). In this paper, we are going to present one particular dimension of this framework, the *structuring theoretical strands*, and we are going to use it in the analysis of three didactical units that have been designed to teach philosophical contents to science teachers.

PRIOR KNOWLEDGE

Science education and didactics of science, that is, the practice in schools and the scholarly discipline reflecting on this practice, have had a development until recently that was scarcely related to the philosophy of science; this situation has been portrayed as a 'mutually exclusive development' of the two fields (Duschl, 1985). Rationales and practical proposals in science education are even nowadays mainly informed by educational and psychological research, largely disregarding ideas coming from the disciplines that study the nature of science. In the last fifteen years, however, this tendency is increasingly being reverted; there has been integration of the fields of science education and the philosophy of science through the work of scholars such as Duschl, Hodson, Lederman, Matthews and McComas (Matthews, 1998).

The study of the different relationships between the philosophy of science and science education constitutes today an expanding area that comprises several very active research lines, such as conceptual change (Nersessian, 1992), nature of science (McComas, 1998), use of historical case–studies (Duschl, 1990), debate around constructivism (Matthews, 1994; Osborne, 1996), and epistemological analyses of didactics of science (Adúriz–Bravo, 1999). These research lines involve the use of different models drawn from the philosophy of science; the adaptations made to these models have proved sometimes to be insufficient or defective (Adúriz–Bravo, 1999), lagging thirty years behind current philosophical debates. As research and development informed by this simplistic or outdated philosophy of science permeate into science educational practice, it can be expected that some science curricula, instructional materials, and science teacher education courses show an incomplete or inadequate view of the nature of science.

In addition to this, there is an enormous amount of evidence showing that prospective and in–service science teachers often lack an adequate view of the nature of science (Koulaidis and Ogborn, 1989; McComas et al., 1998). Teachers' naive epistemological images are generally found to be similar to those developed by the philosophical school of *logical positivism* during the first half of the twentieth century. It has been suggested that these insufficient or incorrect ideas affect teachers' classroom behaviour and influence their students' images of science (Lederman, 1992).

These are powerful reasons supporting the need to closely inspect the teaching and learning of the philosophy of science within the context of didactics of science; we confer high priority to the study and discussion of this issue, taking into account that *the nature of science forms the core of future citizens' scientific literacy*. We are carrying on an attempt of critical inspection of the issue by analysing some of the available proposals to teach the philosophy of science that have been advanced within didactics of science. We have collected over sixty of these proposals to form the data base of our study; to assess them, we have developed a new theoretical framework (Adúriz–Bravo, in press–b). In the following section we outline this framework; the fourth section is devoted to inspect with some detail the particular dimension that we have selected for this paper. We then present three proposals to teach topics from the philosophy of science to science teachers; the proposals are analysed in some depth in order to show explicitly how our construct can be used.

CONTEXT OF OUR INNOVATION

We are concerned with pre– and in–service education of science teachers for the different educational levels from kindergarten to university both in Spain and Argentina. As one of the reviewers of this paper has pinpointed, teacher education courses start from the basis of presupposing in students some knowledge on the nature of science, which should have been acquired during their scientific education. Such assumption is often simplistic and is challenged in our theoretical framework.

This framework aims at assessing proposals that address the teaching of the philosophy of science as an important aspect of science teacher education. Such assessment is done according to several analytical dimensions: dimensions giving factual information on the proposals; dimensions that respond to curricular questions, helping to put the proposal into context; and dimensions regarding the contents of the proposals. Initially, a set of six dimensions provides information that may be of use when retrieving them from their original sources; seven further dimensions characterise the proposals according to their curricular traits:

1. *Populations*. This answers the question: Who are you teaching the philosophy of

science to? There are several populations of students that didactics of science may consider of interest; we have grouped them according to their specific needs in relation to the philosophy of science that they should learn. We talk about three populations: *science students, science teachers, and didacticians of science.*

2. *Contexts*. This answers the question: When and where are you teaching it? McComas and others' (1998) distinguish four contexts in which the philosophy of science can be taught to teachers. We use three, extending them to our populations; these contexts are: *science courses, metascience courses*, and *didactics of science courses.*

3. *Goals*. This addresses the question: What do you expect from this teaching? Some authors analysing the teaching of the philosophy of science as one dimension of science education have recorded different goals (Matthews, 1994; Driver et al., 1996); we suggest that three main groups of goals can be identified: *instrumental goals, specific goals, and cultural goals.*

4. *Method*. The question is: How are you implementing it? This dimension examines the nature of the activities that are used to teach the philosophy of science. Methods include lectures, workshops, lab work, investigations, small group work, dramatisations.

5. *Relationship with a discipline*. The proposals may be related to a specific discipline (physics, chemistry, biology), either because of their contents and examples or because of the population they address.

6. *Content–anchoring*. Some topics of the philosophy of science (such as the hypothetico–deductive method) are a result of a reflection on any or all disciplines, independent of their contents. Other topics are posed by the development of a particular scientific field; for instance, the ontology of quantum mechanics.

7. *Stages*. These are the periods of the philosophy of science that the proposals select to teach, and use as a source. We have developed a scheme that reviews the history of the philosophy of science in the twentieth century, and provides a dynamic picture of the development of this discipline. Our scheme considers three stages that in part overlap:

7.1. *Logical positivism and received view*, roughly covering from 1920 to 1970. The constitution of the Vienna Circle is considered the starting point for our identification of contents. This first analytical approach to the philosophy of science is mainly syntactic, and draws heavily from formal logic.

7.2. *Critical rationalism and the new philosophy of science*, going from 1935 to 1990. Several different schools within this stage may be united because of their profound critique to logical positivism and their introduction of external (i.e. historical and social) considerations.

7.3. *Postmodernism and contemporary accounts*, starting with Paul Feyerabend's radical statements about science in the early 1970s and going on to the naturalised philosophy of science of the late 1990s. This last stage represents a return to classical questions, revisited with new conceptual tools.

In addition to these seven dimensions, we identify the main concepts from the philosophy of science that are addressed in each proposal; for this task, we use a specific theoretical construct, the strands (Adúriz–Bravo, in press–b).

THEORETICAL STRANDS

Our theoretical framework draws on models for science curriculum design that have successfully used the so–called *structuring ideas* (Sanmartí and Izquierdo, 1997). A structuring idea traverses a scientific discipline and permits to organise different specific models around it; in this sense, structuring ideas work as keystones of the science curriculum architectonics. We have imported this design idea to apply it to the teaching of the philosophy of science. In order to analyse the contents from the philosophy of science in the proposals that we have collected, we have developed six sets of structuring ideas; we have called them *strands*. These strands organise the philosophical concepts, models, sources and activities that can be identified within the proposals. We will very briefly elaborate on the strands; more detailed information can be found in another paper (Ad_riz–Bravo, in press–b):

1. *Correspondence and rationality*. This first strand comprises two main aspects of scientific knowledge: the way in which it is believed that theoretical entities and reality fit, and the rational criteria that scientists use to assess this fitting. These two questions have been in the foundations of the philosophy of science since its earliest stages.

Regarding the first matter, several different units of epistemological analysis have been proposed (concepts, models, theories), and two main opposite philosophical views *–realism and instrumentalism–* have been advocated to map these units onto the real world. These two broad views of correspondence have used specific constructs to explain the relationships between theoretical and observational terms (Hempel, 1966). As to the second aspect, traditional philosophers were concerned with the logical structure of scientific judgement; this approach is called *hard* rationality. It was only with the new philosophy of science in the 1960s that external (social and historical) factors were incorporated into the analysis of theoretical choices (Kuhn, 1970).

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. Traditional analyses are theory–based, assuming that theories are at the top of the scientific hierarchy, and that formal disciplines achieve maturity when axiomatically organised. The current *model based view*, derived from a semantic conception of scientific knowledge, challenges this excessively formalist approach (Giere, 1988).

Theories and models as abstract entities are characterised by linguistic propositions that make them communicable, especially through textbooks. This fact has generated the need for a study of scientific language both from traditional discourse analysis and from the new perspective of *rhetoric* (Newton et al., 1999).

3. *Intervention and method.* This strand includes the classical neo–positivistic account of a unique, well–defined scientific method that precedes research and comprises a fixed series of steps, starting from observation and ascending to scientific laws. Several variations to this scheme have been proposed since the 1930s, including Popper's (1963) very elaborate *falsificationism.* Among recent contributions to the discussion, we highlight methodological models that focus on the construction of paradigmatic experimental facts through writing (Izquierdo, 1994); these models partly stem from the new sociology of science and are of great interest for didactics of science.

4. *Contexts and values.* This strand regards the relationship between science and the general social, cultural and educational contexts, which are characterised by their own aims and values. Traditional accounts have disregarded such relationships advocating a strong *neutrality* for science. Science was portrayed as a value–independent activity aimed at the discovery of truths about the world that are of value by themselves, independent of their use, sources, power and consequences. More recent views on the social nature of science frontally challenge these assumptions; philosophers add to the classical contexts of discovery and justification those of innovation and education, proposing an axiological study of the scientific endeavour (Estany, 1993).

5. *Evolution and judgement.* This strand involves a diachronic study of the theoretical entities that constitute the core of science. The traditional philosophy of science sketched a rather static picture of the scientific enterprise, producing a cumulative view that disregarded the study of the mechanisms of *conceptual change.* New models, following Kuhn's (1970) account of scientific revolutions, focus on the nature of knowledge shifts. Another aspect of interest to analyse scientific evolution is the study of the ways in which scientists make reasonable choices between competing explanations. In this issue, the contributions of the cognitive philosophy of science (Giere, 1988) are of the utmost relevance, as they propose a *naturalised* approach to the concept of rationality.

6. *Normativity and recursion.* This last strand focuses on the recursive, metadiscursive nature of the philosophy of science, that is, on the fact that the discipline is a second order discourse theorising about science that can turn onto itself to perform a self–analysis of its own validity and reach (Estany, 1993). This so–called *metaphilosophical* analysis permits to distinguish between a strongly normative approach to the discipline, in which general a priori parameters are sought, and an explanatory approach, considering the philosophy of science as another empirical discipline.

ANALYSIS OF PROPOSALS

During our work with teachers, we have collected and adapted several existing proposals to teach different philosophical topics; these proposals are addressed to various populations within the context of science education and are available in the existing literature (for instance, in McComas, 1998). Many of these proposals are directed to the improvement of the teaching of various scientific contents (Abd–el–Khalick and Lederman, 1999), but we are here concentrating only on the aim of teaching the philosophy of science per se, independent of such derivations. We will now analyse three proposals that have been issued for the purpose of teacher education in specific topics of the philosophy of science, showing explicitly how they address the theoretical strands exposed above.

Scientific reasoning and detective novels

This first didactical unit (Ad_riz–Bravo, in press–a) is aimed at the teaching of a set of central concepts from twentieth–century philosophy of science, such as *explanation*, *reasoning* and *inference*, that are considered important within science education (Duschl, 1990; Newton et al., 1999). This is done by using a world–famous detective novel, Agatha Christie's *Death on the Nile*, in book and film format. We oppose Christie's construction of the narrative (by means of deductive reasoning) to Hercule Poirot's solution of the criminal enigma, which draws heavily on *abductive* patterns. Classical logic, modelling, and the role of reasoning and creativity in scientific discovery are examined through paper–and–pencil tasks and small group discussion.

Models of *correspondence* from stages 1 and 3 are constantly opposed using an analogy that compares detective investigation and scientific inquiry; the syntactic approach, typically developed by logical positivism, is compared to the semantic approach, characteristic of contemporary schools such as the cognitive philosophy of science. The opposition between these models is achieved through the analysis of three kinds of inferences: deduction, induction and abduction. Traditional philosophy of science has concentrated on the opposition between inductive and deductive reasoning, combining both in the *Aristotelian method* (Hempel, 1966), which is in the base of many well–known introductions to the nature of science in textbooks and courses. Abduction as a logical mechanism for scientific explanation has been largely disregarded in the philosophy of science and in science education, but it is currently recognised as a core element in the process of scientific modelling (Giere, 1988; Thagard, 1992) that should be taught at school. This proposal recovers abductive reasoning as a powerful formal analogy of the process of modelling.

With the emergence of a semantic conception of theories within the philosophy of science in the last thirty years, a *model based* view was developed (Giere, 1988), and subsequently moved to the areas of cognitive science and didactics of science (Duschl, 1990). This philosophical approach is interested in how theories are produced and selected, how they make sense to scientists, and how they are used and learnt, rather than in their mere formal structure of deductively concatenated axioms. Within this conception, models are the key entities of theoretical thinking; scientific modelling can be regarded as a process of abduction from theory–laden evidence to abstract theoretical organisations (Giere, 1988; Thagard, 1992).

This proposal has adapted original sources from philosophy of science (among others: Samaja, 1994), a procedure that is yet uncommon in science education but that has been heavily recommended (McComas, 1998). These sources are introduced together with their application to the narrative, in order to effectively anchor the analogical process. We will present here a sketch of the proposal with its main features. The activity begins by exploring the structure of classical detective novels in terms of its key elements: crime, suspects, clues, investigation. A first approach to the formal structures of Hercule Poirot's solution to the mystery and Agatha Christie's construction of the plot is asked from teachers. Later on, formal argumentation patterns for the three main kinds of inferences are presented; here we use Samaja's (1994) Spanish version of Charles Sanders Peirce's (1967) canonical presentation, as follows:

* Three statements are considered: *p*. All the beans from this bag are white; *q*. These beans are white; and *r*. These beans are from this bag.

* These statements are combined in the following three inferential patterns: *I*. If *p* and *r*, then *q*; *II*. If *q* and *r*, then *p*; *III*. If *p* and *q*, then *r*. Pattern *I* is called deduction, pattern *II* is called induction, and pattern *III* is called abduction. Abduction can also be structured in the form of a categorical syllogism, in which the if–clause is called by Paul Thagard (1992) a *rule*.

Instances for the three ways of reasoning are extracted from the book, and with this framework, the author's and the character's procedures are opposed: abduction is presented as a "reverse" deductive mechanism, or an ascending inference starting from incomplete evidence. The instructional unit ends with the transposition of these content–free apparatus to specific examples from science; among these, we have used the relationship between evidence and models in the fields of atomic structure and interior of the Earth.

The pendulum as an international standard of length

This second didactical unit has been elaborated by Michael Matthews (2000). It uses some episodes selected from the history of modern science to illustrate the rich contextual relationships between science, technology and society. This example initially concentrates on Christiaan Huygens' late seventeenth century proposal to adopt the *seconds pendulum* as an international standard of length, relating this issue to strategic problems such as measuring longitude at sea, achieving accurate time–keeping, or simplifying commercial weights and measures.

One of the aspects that this proposal deals with in detail is the question of why the French revolutionaries chose the expensive and time–consuming geodetic determination of the metre when Huygens' chronometric determination had been readily available for over a century. This question allows the author to deeply combine topics from the strands of intervention and method, and contexts and values; he critically examines some key matters about the topic of *theory testing*, and about the interrelation games between science, politics and economy.

Dialogue between two pharmacists

This third didactical unit (Izquierdo, 2000) concentrates on the strands of contexts and values, and evolution and judgement. Within the classical genre of a dialogue between two (not so) imaginary scientists, widely used in philosophy and didactics of science, an extensive and elaborate text opposes two historical views on pharmacy, the *botanical* and *iatrochemical* conceptions. The scene, set in Paris in the early seventeenth century, highlights the underlying general (philosophical, religious, aesthetic) values of these two views; such values to a great extent determine the scientists' theoretical and methodological commitments, obstructing "objective" exchange between them.

The problem of theoretical change is also examined through opposing two research traditions and their supporting powers, interests and institutions. The goals of this proposal are achieved by means of a dense historical setting that provides the readers (in–service teachers) with tools to enact and further develop the proposed situation.

CONCLUDING REMARKS

This paper is based on the acknowledgement that the philosophy of science is a fundamental component of future citizens' scientific literacy, and consequently must be infused into science teacher education. Current programmes show several shortcomings in their philosophical basis; the theoretical tool that we have presented intends to help in the improvement of such programmes.

Our theoretical framework is enhanced when combined with other models to identify key issues in the philosophy of science and to evaluate proposals to teach them (for instance, Loving, 1998; Abd–el–Khalick and Lederman, 1999). We have found that the set of strands may work as a very powerful didactical tool, as it provides science teachers with an extensive overview of the philosophy of science that makes it more meaningful, and allows them to seize the relevance and usefulness of philosophical contents for their professional development and for the preparation of future citizens. In science teacher education, strands also help us do a *pragmatic* selection of contents from the philosophy of science that is informed by didactics of science, and combines elements from competing research lines.

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