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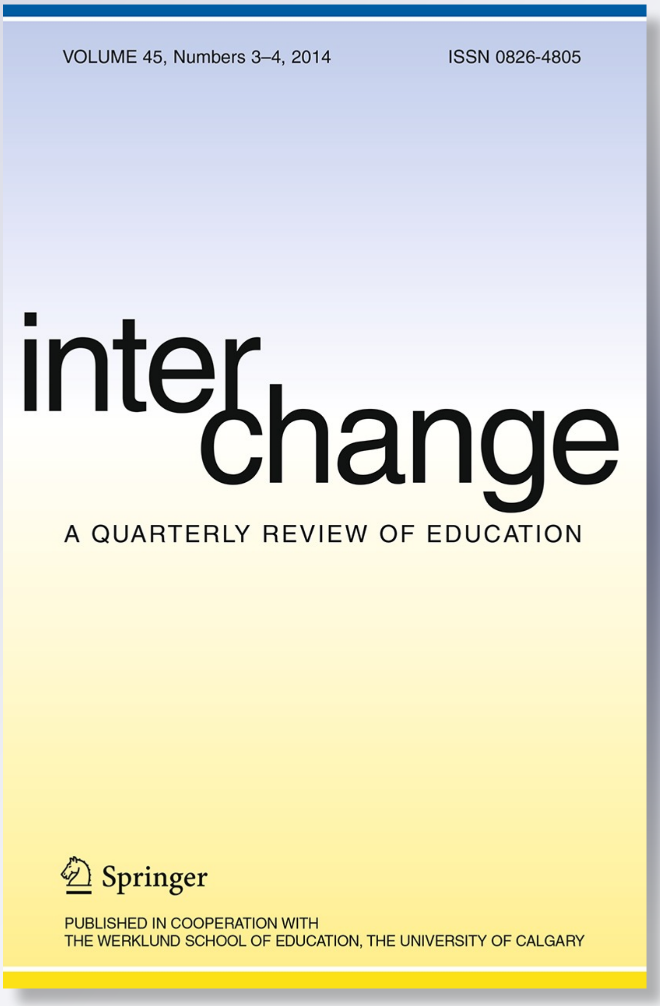

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Teaching the Nature of Science with Scientific Narratives

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Abstract The aim of this paper is to discuss the use of short science stories based on the history of science for science teacher education. Such stories are implemented to acquaint prospective and practicing science teachers in all educational levels with a conceptualisation of the nature of science (NOS) drawing from recent and contemporary developments in the philosophy of science (namely, the lines of new experimentalism and semantic conception of scientific theories). Science stories are here understood as narratives combining different 'rationalities', i.e. ways of presenting the scientific content in different stages of production and under different syntactic formats. In our work with teachers, the scientific enterprise is depicted as an aim-driven, value-laden transformation of the natural world mediated by conceptual and material tools; in such depiction, theoretical models are given a central role. The paper presents a didactical (i.e. instructional) unit with such conceptualisation of NOS; this conceptualisation is set against the backdrop of some scientific narratives on the history of the atomic theory that are embedded in the unit.

Keywords Nature of science · Narratives · History of science · Rationalities · Intervention · Instructional unit

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Introduction

The aim of this paper is to discuss the use of scientific narratives in order to present a depiction of the nature of science (standardly abbreviated as NOS) that may be of value for science education. 'Science education' is understood in its two senses: the practice of teaching science in the science classrooms, and an academic discipline investigating such practice (for this second sense, the expression 'didactics of science' will be employed, as it is usual to do in the continental tradition: Lijnse 2000). The depiction of NOS proposed here is especially targeted to the education and professionalization of prospective and practicing science teachers.

The paper addresses the nature of science 'as a whole', i.e. it intends to present a *functional* and *interpretive* characterisation of the scientific enterprise (cf. Allchin 2011), as opposed to a series of separate features contained in a list of 'NOS tenets'. The view on NOS presented here draws mainly on contributions from two recent trends of philosophy of science (from the 1970 to 1990s): the *post-Kuhnian philosophy of science* and the *semanticist family*.

This paper resumes previous proposals to implement the use of short science stories based on the history of science (Adúriz-Bravo 2011; Revel Chion et al. 2013); work by Mercè (Izquierdo-Aymerich 2010, 2014) suggesting the combined use of a 'logical rationality' and a 'narrative rationality' is retrieved to construct the stories. The science stories are conceptualised here as *narratives* striving to intertwine or hybridise the aforementioned rationalities by means of the use of abductive reasoning, sometimes called 'inference to the best explanation' (cf. Adúriz-Bravo 2001, 2003, 2005b).

The paper discusses the design of a didactical (i.e. instructional) unit directed to acquaint pre- and in-service science teachers for all educational levels (from Kindergarten to University) with the NOS construct of 'science as intervention'. In that unit, and following some writings by philosophers of science such as Ian Hacking (1983) and Javier Echeverría (1995), the scientific activity is portrayed as an aim-driven, value-laden transformation of the natural world aided with, and mediated by, *material tools* (instruments) and *symbolic tools* (concepts).

Selected episodes from the history of science (in particular, some key moments in the history of atomic theory: cf. Izquierdo-Aymerich and Adúriz-Bravo 2009; Adúriz-Bravo 2014) provide materials for the narratives composed to work with science teachers. The kind of work suggested here can be conceptualised as school *meta-scientific argumentation*, i.e. teachers argue around the 'interventive' nature of the scientific activity in some specific contexts that are rich enough to support critical discussion.

The paper is structured in two long sections. The first one contains the NOS proposed for science teacher education; the second describes the unit and addresses the construction of the narratives. Some general remarks are included at the end.

A Depiction of the Nature of 'Whole Science'

This section presents the view on NOS that is assumed to be of formative value for science teachers. The first subsection is devoted to identifying some 'key ideas' (cf.

Adúriz-Bravo 2007) from the philosophy of science that might be worth sharing with science teachers in view of what contemporary science curricula mandate to teach. The second subsection utilises those key ideas to produce a compact characterisation of science: the scientific enterprise is depicted as *a model-based intervention on the natural world*. It is the contention here that such depiction is valuable in order to conceive and design school science, i.e. a robust 'didactical transposition' (cf. Lijnse 2000) of the science to be taught that has educational aims.

A characterisation of school science as intervention constitutes a 'meta-model'[1] of the scientific activity; it captures different aspects of its *processes* and *products*. These processes and products would include some of those mentioned by Douglas Allchin when he defines an 'articulated' and 'inclusive' NOS:

> In recent years, treatment of NOS in some places has yielded to more particular discussion of 'science as a way of knowing' (or 'how scientific knowledge is constructed,' 'scientific inquiry,' or 'the scientific worldview'), 'scientific practices' or the 'scientific enterprise,' and 'how science works' […]. For teachers and curriculum designers, any *articulation* of the vague and general phrase 'nature of science' is surely welcome. The notion of *Whole Science* echoes and extends efforts to characterize NOS *inclusively*. (Allchin 2011, p. 526, emphasis added)

Two Artefacts to Teach NOS

This subsection contains two didactical 'artefacts' devised to be used when teaching the nature of science to science teachers. The first artefact permits to identify and locate—in the history of the philosophy of science—key ideas that are valuable to construe NOS in science education. The second artefact includes some organised elements around the inferential, model-based nature of the scientific activity when understood as mediated intervention.

The first artefact (Fig. 1) is called the 'fish', and intends to be a schematic representation of the history of professional philosophy of science in the 20th century. It features some of the main currents, schools and lines of the discipline, with their temporal sequence and intellectual relationships.

The fish should be read from left to right, as if superimposed to a (horizontal) time axis. The fish's backbone represents what could be considered the 'hegemonic' current in the philosophy of science: its first stages as a professionalised discipline—i.e. logical positivism, proposed by the Vienna Circle–, ranging from the 1920s until World War II; the 'received view' in the 1940s–1960s, mainly developed by English-speaking scholars; and—in the last decades—neo-positivistic perspectives following the analytic tradition.

In the periphery of this central line containing mainstream philosophy of science, and 'protruding out' of the backbone, there appear:

[1] A meta-model would be a scientific model produced in a 'meta-science', i.e. a scientific discipline studying science, such as the philosophy of science, the history of science, and the sociology of science. These are called meta-sciences due to the fact that they inspect science from a second-order (*meta-discursive*) perspective.

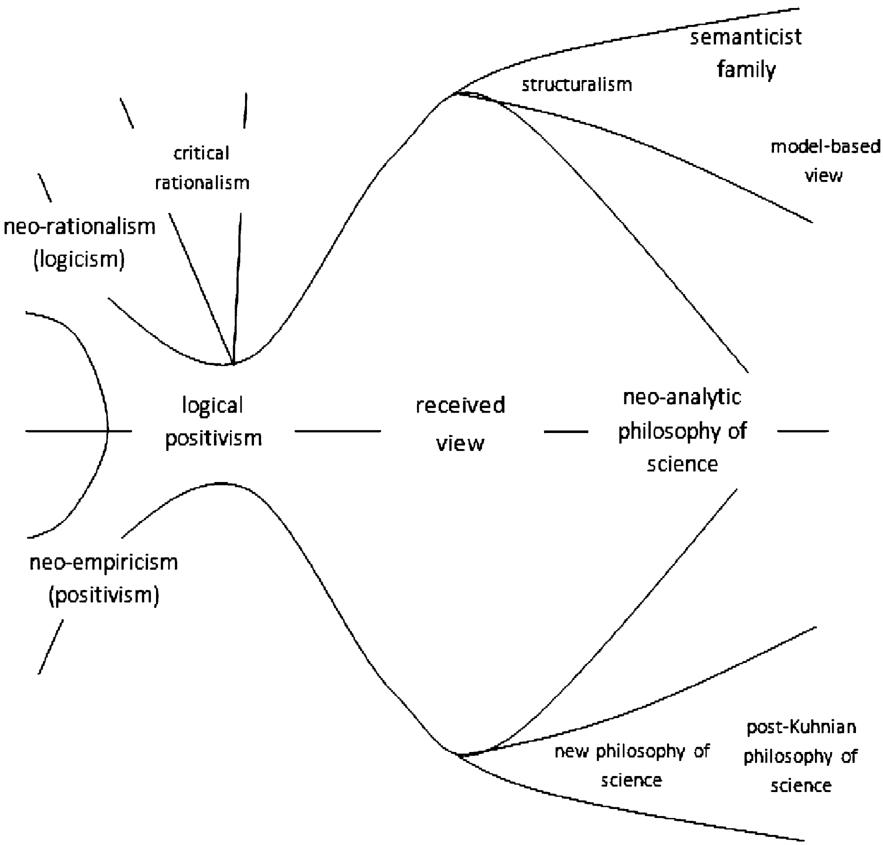

Fig. 1 The 'fish': a schematic representation of the history of the philosophy of science in the 20th century

1. Early critiques to logical positivism, grouped under the broad label of 'critical rationalism', and including authors such as Karl Popper and Gaston Bachelard.
2. The then 'new philosophy of science', starting in the early 1950s, and intending to be a plausible alternative to the rapidly declining received view (cf. Suppe 1977). This current first comprised a more 'internalist' line, with authors such as Quine, Putnam and Hanson, and—a few years later—a 'historicist' version, grouping Thomas Kuhn, Imre Lakatos and Stephen Toulmin, among others. A more recent version of this current, vaguely called 'post-Kuhnian philosophy of science', gives stronger emphasis to the historical and sociological aspects introduced in the 1960s, and shifts the focus to the study of scientific practices, values and language.
3. A whole current interested in the concept of scientific models, here called 'semanticist family' (Lorenzano 2003). This current would include a diversity of lines: meta-theoretical structuralism, the semantic view of scientific theories, and model-based approaches.

Figure 2 intends to show the use that didactics of science has made of the diversity of schools of the philosophy of science captured in the fish. From the late 1980s, interest in our discipline was mainly turned to the new philosophy of science, especially in its historicist version, with Kuhn featuring as a main reference (cf. Matthews 2004). Consequently, previous schools in the philosophy of science were hastily discarded, with the argument that they represented traditional, *positivistic* approaches to the study of science, of little or no use in science education. In addition, authors publishing after Kuhn (and his supporters and opponents) were also disregarded, mainly due to the limited background that didacticians of science (i.e. science educators understood as academic researchers) have in recent and contemporary philosophy of science.

Figure 3 highlights the key ideas of the philosophy of science that constitute the main source of epistemological materials for the NOS discussed in this paper. These ideas proceed from currents, schools and lines *after* the new philosophy of science, i.e. from recent and contemporary accounts that are very seldom referenced in didactics of science. On the one hand, post-Kuhnian philosophy of science of the 1970s–1980s helps shift the interest from science products to science processes, giving value to the transformative, interventional activity of science on the natural world. On the other hand, the semanticist family of the 1980–1990s, with its detailed characterisation of scientific models as modes of theoretical representation, provides new elements to understand the conceptual mediations introduced by theories when thinking about reality.

The constructs highlighted in Fig. 3—intervention and model—provide the foundations for the second didactical artefact. This artefact (Fig. 4) is called the 'mill': it purports to be a model-based account for intermediated processes in science of instrumental and conceptual character. The four processes captured in the 'mill' are grouped under the label of 'scientific investigation'. All these processes, on the one hand, are aided by, and mediated through conceptual tools deriving from the scientific theories (and models) employed—and, in this sense, they can be characterised as 'model-driven' processes. And, on the other hand, they are aided by, and mediated through material tools—the scientific instruments that are increasingly being utilised to intervene on the natural world (cf. Heering and Wittje 2011).

Didactics of science has contemplated the nature of science from a broad range of perspectives, mainly coming from the meta-sciences, but also from some other meta-theoretical studies (science-technology-society, science studies, sociology of scientific knowledge, gender studies, etc.). Because of this diversity of sources, it has been pointed out both by philosophers and by didacticians of science that there is no such thing as 'the' nature of science. NOS can be construed in quite dissimilar ways (cf. Matthews 1998, 2012; Allchin 2011; Maurines et al. 2014), ranging from lists of general features to sets of philosophical models. NOS can also be focused on a diversity of specific issues, such as demarcation, theories, experimentation, values, explanation, gender, etc. A semantic, model-based view of scientific theories, taken from the philosophy of science of the last three decades (cf. Suppe 1977; Adúriz-Bravo 2013), is the one favoured here. To this approach, the idea of instrument-mediated activity is added.

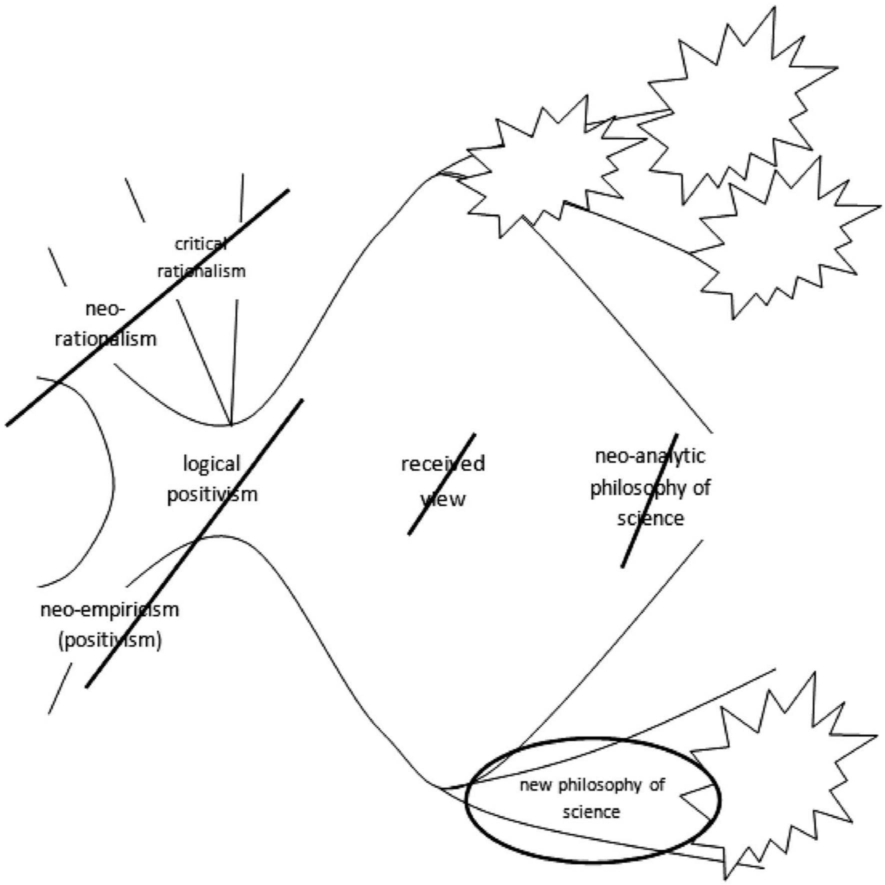

Fig. 2 The philosophy of science as it has been used in didactics of science. The new philosophy of science (*circled*) has been the favoured choice from the 1980s until very recently. Previous schools (*stricken out*) were rejected under suspicion of having a 'positivistic' flavour. More recent schools (*obliterated*) are not yet well known amongst didacticians of science

Philosophical accounts of science have usually concentrated in characterising it as a set of products: scientific knowledge as the product *par excellence*, but also data, values, artefacts, publications, etc. From a semantic perspective, theoretical models emerge as one of the most interesting scientific products, with direct implications in school science (Adúriz-Bravo 2013).

But, in addition to this, science comprises a diversity of processes, which were functionally designed and adjusted over history in order to generate the aforementioned products:

> Historians of science (…) generally believe that in scientific discovery there is a spectrum of scientific involvement that ranges from identifiable mechanical procedures to high-grade activities involving the educated scientific imagination of the research scientist that cannot be captured by any "scientific method." (Stinner et al. 2012, p. 54)

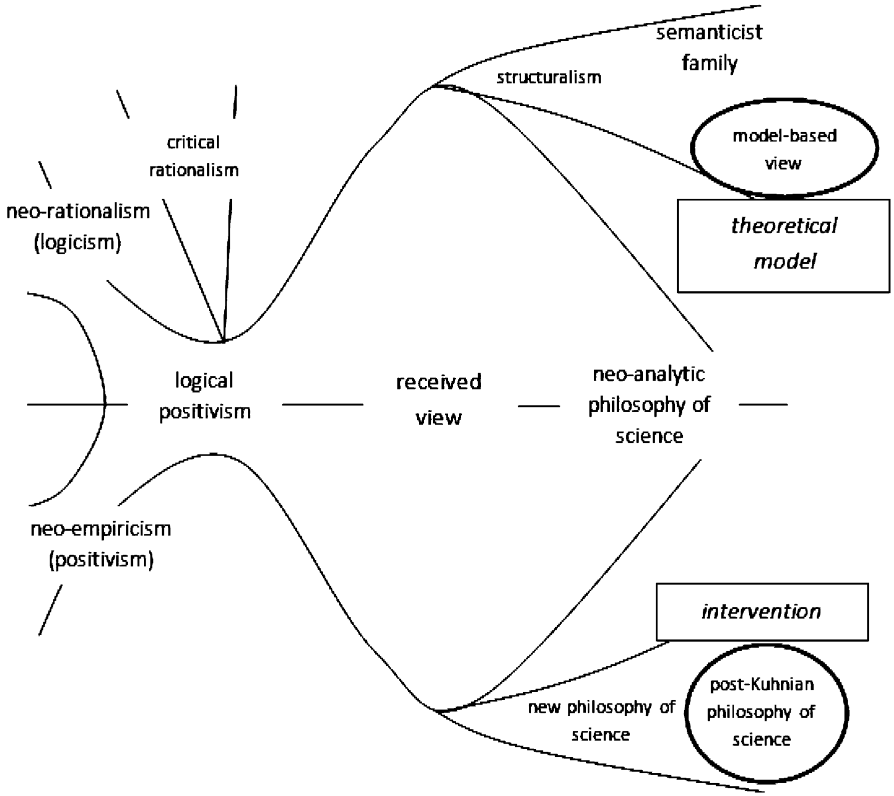

Fig. 3 Schools of the philosophy of science from the 'fish' that have been selected for the NOS in this paper (*circled*), together with the main philosophical constructs (in *italics*) taken from them to build up the theoretical framework

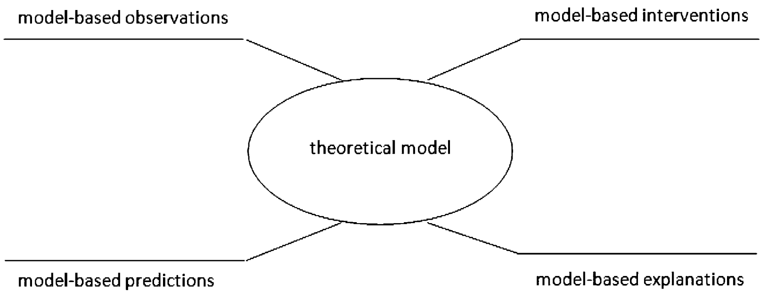

Fig. 4 'Model-driven' scientific investigation. It comprises at least four processes (observation, explanation, prediction, and intervention) based on the use of theoretical models

Among those scientific processes, innovation, justification, validation, application, evaluation, teaching, and communication are included. Intervention, i.e. an appropriative transformation of reality, is chosen here as one salient process that deserves to be discussed with science teachers.

In this paper, the idea of 'scientific investigation' is used to designate science processes at a very general level, but not conflating it with science-in-the-making as a whole (which would also include societal demands, financing agencies, rivalry between institutions, dissemination, etc.). The term 'investigation' comes from the Latin 'investigare', with the meaning of *follow trails*; this etymological connection is here used from a didactical point of view. It is suggested that the puzzle-solving, evidence-based nature of science (cf. Adúriz-Bravo 2001; Lawson 2010) should be highlighted when working with science teachers.

As it was said, scientific investigation produces as one of its most recognisable outcomes some highly structured propositions about the world, but a prominent feature of science is that it always requires reasons to sustain those propositions. During investigation, scientists produce or obtain 'compelling' elements in favour of our understanding of reality. In the NOS proposal presented here, school scientific investigation is portrayed as the collection, structuring and use of evidence in order to support a scientific view on a natural phenomenon.

Scientific enquiry is another construct that has been extensively used in didactics of science. Flick and Lederman (2004), for instance, have been pointed out that enquiry and NOS are intimately related, and yet conceptually separable. In the nature of 'whole science' approach adopted here, scientific enquiry is used more or less as a synonym of scientific investigation. In fact, enquiry, just as investigation, can be suggestively conceptualised as an evidence-related construct; the noun 'enquiry' comes from the Latin verb 'inquaerere', with the meaning of *seek* or *ask*.

Investigation/enquiry will be here understood as the model-driven collection of evidence: an activity in which theoretical models guide, and even 'load', our observation, explanation, prediction and also intervention on phenomena (Fig. 4). In this sense, the use of theoretical models would give structure, coherence, and direction to intervention.

The process of investigation/enquiry, when regarded as evidence-based, can be profitably connected to the use of *inferences* (i.e. modes of reasoning or thinking) that belong with abduction in its most general sense (cf. Adúriz-Bravo 2001, 2003, 2005b). Thus, when working with teachers, it could be a particularly fruitful strategy to draw an analogy between scientific reasoning and other activities that are aimed at puzzle-or mystery-solving and make use of abductive patterns; among those, detective, medical, forensic, and 'gossipographic' (i.e. garden-variety) thinking seem of utmost interest. In all these fields, a parsimonious collection of 'facts' gathered under the guidance of a strong model can be used as premises of a logically 'ampliative' reasoning process, which 'ascends' to general, abstract and audacious conclusions with intended explanatory power.

The parallelism between detective and scientific thinking is exploited in the didactical unit discussed here; scientific intervention and scientific models are given specific roles in this framework and become substantive pillars of NOS.

Science as Mediated Intervention

The key ideas on NOS in the previous subsection can be put together in order to define a meta-model of 'whole science' for science teacher education. As Allchin remarks,

> Whole Science may well designate a synthesis not only of relevant NOS elements, but also of scientific process and product in an educational context. Whole Science in a classroom embraces content, process of science skills, and broad-ranging NOS analysis. (Allchin 2011, p. 533)

In order to construct this embracing synthesis that allows analytically thinking about science, it is suggested here that the conceptual 'cement' can be the focus on the 'interventive' nature of the scientific activity. Post-Kuhnian philosophy of science [i.e. authors after 1970 in the historicist and sociological 'turns' set off by *The structure of scientific revolutions* (Kuhn 1962)] provides the theoretical foundations for such focus.

A key trait of this post-Kuhnian philosophy of science has been to devote attention to issues and problems disregarded by classical philosophy of science (cf. Estany 2007). One of the 'invisibilised' elements of the scientific activity that was recovered by post-Kuhnians was the 'real' scientific experiments, as opposed to the highly stylised 'hypothesis-testing' experimentation within the scientific method that had been proposed by the received view. Thus, in the last decades, philosophers of science, as well as

> [a] growing number of historians and sociologists, and not a few scientists, […] want to show why experiment is more interesting and more important than traditionally realised. This importance warrants careful attention rather than honorific neglect. (Gooding et al. 1989, p. xv)

This academic tendency that has striven to re-locate experimental activity at the core of our understanding of science is usually referred to as 'new experimentalism' [an expression most probably coined by Ackerman (1989)]. The interest of new experimentalists,

> from the very beginning, centred philosophical analysis on the scientific practice as a whole, instead of focusing it only on the results of this practice, namely, on the scientific theories. This implies taking into account other factors that intervene in science-in-the-making, such as material infrastructure, instruments, human interactions, relations with the administration, etc. Although these factors are not completely independent, they have different incidence, and to different degrees, on the internal dynamics of science. (Estany 2007, p. 37, my translation)

One of the most influential authors in this line of new experimentalism has been Ian Hacking, with his critique to positivistic philosophies of science for their "single-minded obsession with representation and thinking and theory, at the expense of *intervention* and *action* and *experiment*" (Hacking 1983, p. 131, emphasis added). Other relevant contributions come from Shapin and Schaffer (1985), Peter Galison (1987), and David Gooding (cf. Gooding et al. 1989) and, more recently, from Andrew Pickering (1995) and Javier Echeverría (1995). In didactics of science, Heering (cf. 2007, Heering and Wittje 2011, Heering et al. 2013) has focused on the experimental traditions in the scientific activity and has advocated for a more careful study of the 'material cultures' of science and the uses of instruments and experiments in the history of science education.

In order to characterise the philosophical approach of new experimentalism, Madrid Casado (2006) suggests the metaphor of the scientist as *musician* or as *architect*. According to him, scientists do not 'collect' the world (as in the Popperian metaphor of scientists as *fishermen*), nor do they 'represent' it (as in the Galilean metaphor of scientists as *painters*). Rather, they 'compose' or 'construct' the world, in a much more proactive fashion. Hence, science can be understood not as our knowledge of how the world is, but as our knowledge *of what we have done, or can do, to the world*.

But such knowledge of our intervention on nature is located in, and framed by, a particular place and time –it is embedded in a culture. Hence, science becomes an intervention that is:

1. *Aim-driven* it takes its very meaning from the diversity of goals pursued by society in general and by the scientific community in particular, with such goals broadly transcending the will to understand nature.
2. *Value-laden* it is traversed by the epistemic and ethical values consensually sustained in each moment of history.

As said before, scientific intervention entails the construction and use of theoretical models, which give rise to a range of conceptual and symbolic tools that act as mediators in our activity on the world (this is what Ibarra and Mormann (2006) call 'representational intervention'). But intervention also embodies the material culture: the technical (in its broadest sense, akin to 'artistic') capabilities that the scientific community has in order to extend and refine the interaction with reality.

Considering school science as a mediated intervention would constitute a 'whole science' approach to NOS in at least two respects. In the first place, this statement permits inspecting many important philosophical ideas (science processes, mediation, tools, symbols, models, aims, values, culture, history, etc.). Secondly, it allows a more balanced treatment of the *theoretical* and *experimental* aspects of the nature of science, which usually result divorced when over-emphasising a rationalist or an empiricist perspective.

A Didactical Unit

This section presents the 'didactical unit' (i.e. teaching–learning sequence) that has been designed to acquaint teachers with the 'interventive' nature of science. As advanced in the previous sections, the unit profits from the analogy between scientific and detective investigation. The first subsection is devoted to describing the general structure of the unit; the second focuses on the 'science stories', i.e. the narratives based on the history of science that constitute the scenarios for NOS learning.

The Structure of the Unit

The didactical unit discussed here is called 'Formaldehyde guests' (in Spanish, 'Pensionistas en formol'), and revolves around the model-based inferential processes captured in the 'mill'. It is used with prospective and in-service science teachers for all educational levels in courses of Didactics of Science (i.e. Science Education Methods), Philosophy of Science, and Nature of Science.

The unit uses as main resource the short story 'The landlady', by the Welsh fiction writer Roald Dahl, first published in 1959 in *The New Yorker*. In this story, as in some other of his writings, Dahl uses techniques and resources that can be directly related to the psychoanalytic concept of *das Unheimliche* (the uncanny). An uncanny thing—following Sigmund Freud's conceptualisation—belongs to the class of frightening things that take us back to what is familiar and old-known (cf. Peel 1980), and thus the English etymological equivalent of 'unhomely': the natural that becomes horrific. In 'The landlady', a seemingly innocent situation (namely, a young man taking a room in a boarding house) is progressively perceived by the readers as utterly disquieting, and at the end mapped with a horror story.

In the unit, participant teachers are asked to perform a series of paper-and-pencil tasks, which are to be solved individually, in small groups, or in the whole class. Theoretical reflection on those tasks is conducted in order to discuss the NOS model presented above. The structure of the unit is as follows:

1. Teachers first read the story (from Dahl 1979). This is usually done as home assignment, or in the first 15 min of the lesson.
2. Someone volunteers to retell it in front of the class. The story revolves around the main character's (Billy Weaver) journey from London to Bath and his subsequent meeting of the title character, an incongruous middle-aged lady who offers 'bed and breakfast' at her home. A series of incidents of increasingly sinister nature occur in the story; through the deployment of various *unheimlich* elements, Dahl builds up the tension and smoothly but inexorably guides the readers to the inference of an evil *dénouement*: Billy will be poisoned, embalmed, and stored by the landlady with other, previously murdered, young men.
3. Then they solve the paper-and-pencil tasks. Those tasks demand from teachers a hypothesis—the reconstruction of the *unheimlich* ending of the story (intentionally omitted by Roald Dahl in his piece)—, and an argument to support such hypothesis. Teachers are required to answer questions such as: what will happen to Billy?, why do you think that would happen after the actual end of the story?, and what would you do to be sure you are right?
4. They reflect on what has been done along the first two steps of the unit. As the retelling takes place, the instructors make notes on the blackboard. With those notes (Fig. 5), teachers can see that the storyline has been reconstructed by the volunteer according to their expectations, assumptions, background knowledge, prejudices, etc. Therefore, at the end, the obtained version has drifted apart from the original in some significant aspects (Fig. 5):
    4.1. Teachers select only some of the elements of the tale, those that they deem relevant to sustain the plot.
    4.2. Teachers present those elements in linguistic formulations that differ from their textual counterparts, and are better adjusted to their own conception of the story.

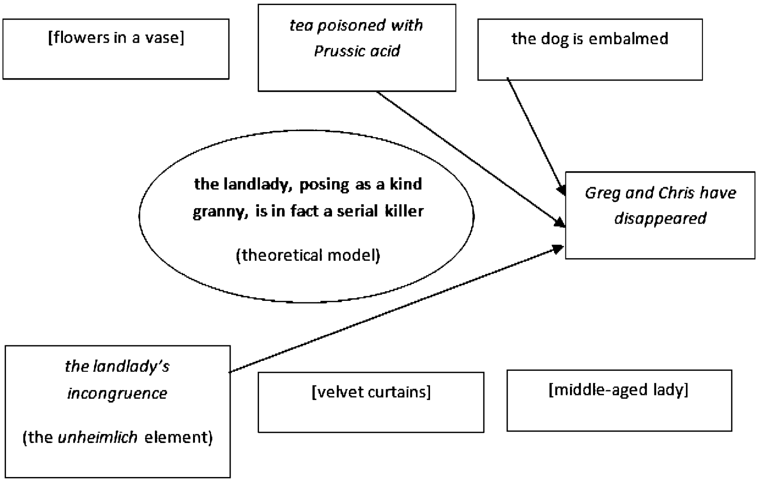

Fig. 5 A diagrammatic representation of the changes that teachers introduce in their re-telling the story in the didactical unit. In *square brackets*, examples of some elements of the story omitted by the teachers. In *italics*, examples of some elements of the story transformed (via a process of model-ladenness) by the teachers. *Arrows* show inferential relationships added by the teachers

4.3. Teachers link some of the juxtaposed elements of the story in a tighter, more *causal-like*, structure.

5. Then the 'mill' is introduced as a tool to characterise and label all the 'operations' performed by teachers during the previous tasks (Fig. 6). The selection and transformation of the pieces of the story would correspond to model-based observations. The introduced inferential structure could be considered a model-based explanation. The possible ending hypothesised when demanded would be the model-based prediction. Finally, the courses of action suggested by the teachers in order to 'prove that they are right' about the ending could be seen as model-based interventions.
6. Relying on the 'mill', teachers draw an analogy between the more 'detective-like' version of the story (i.e. after it has been retold) and scientific investigation. They think about some paradigmatic episodes of scientific investigation (*epitomes* of discovery and invention) in terms of the 'operations' recognised in the non-scientific context. This is the place where the narratives (science stories) embedded in the unit are used to convey historical data (see the next subsection). Following each narrative, one or two specific aspects of the model of science as intervention are discussed.
7. At the end of the unit, they make explicit connections with teaching practices. The group of teachers reflect on the implications of this view on NOS for science education. Some 'ways of doing' in the science classroom are proposed, mainly regarding the use of scientific narratives based on the history of science and the detective-scientist analogy.

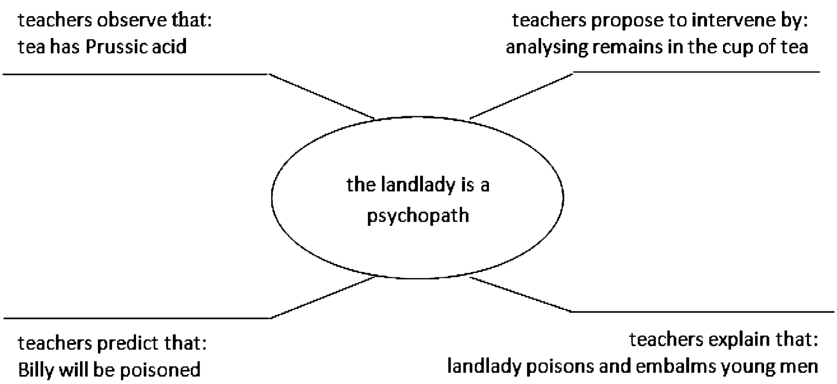

Fig. 6 The 'mill' is used to characterise teachers' 'operations' on the tale. At the end, the *plot* resembles a detective story much more than the original

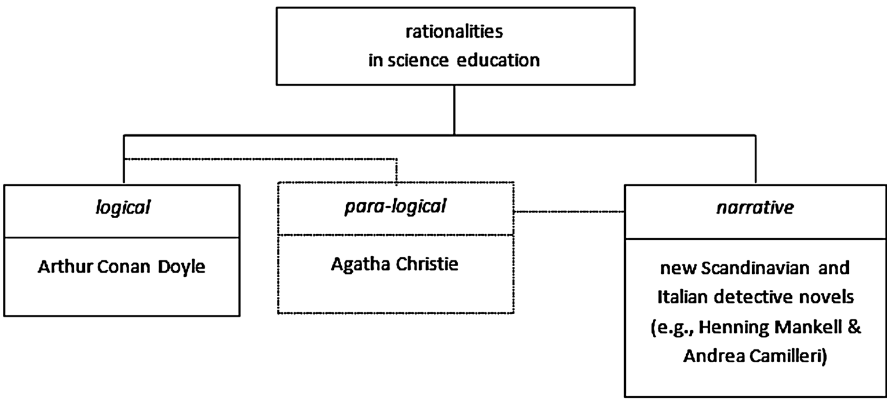

Fig. 7 Izquierdo-Aymerich proposes two main 'rationalities' that can be used in science education: the logical and the narrative. She identifies them with two 'styles of thinking' in detective novels. A third, 'hybrid', rationality is added here

The Scientific Narratives

Following ideas by Bruner (1996, chap. 6) and Gardner (1991, part III), Mercè Izquierdo-Aymerich (2010, 2014) proposes the existence of two main 'rationalities' of science present in, and suitable for, science education. Rationalities should be here understood as ways of telling or presenting scientific content in different epistemic stages of production, and through different syntactic or structural formats. Izquierdo-Aymerich talks about a 'logical' rationality and a 'narrative' rationality (Fig. 7).

Logical rationality would give shape to science *in its final form*, based on conclusions; its main aim would be to demonstratively explain the natural world. Logical rationality would thus be identifiable with verification (Fisher 1994) in the famous 'context of justification', with its *nomothetic* (i.e. law-oriented) character and its demands for nomological-deductive explanations.

Narrative rationality would characterise the *development* of that final-form science, introducing the 'human' factor and rhetorical elements. Narrative rationality, which is historical and situational (Fisher 1994), would correspond to the 'context of discovery', and would seek for genetic, historical or teleological explanations. This makes narrative rationality intrinsically *idiographic* (i.e. anchored in the unique nature of each case):

> Unlike the constructions generated by logical and scientific procedures that can be weeded out by falsification, narrative constructions can only achieve "verisimilitude." Narratives, then, are a version of reality whose acceptability is governed by convention and "narrative necessity" rather than by empirical verification and logical requiredness (…). (Bruner 1991, p. 4)

In order to explain these two kinds of rationality, Izquierdo-Aymerich also resorts to the analogy between scientific and detective thinking; she attempts at identifying the rationality models in the structures of famous detective novels (Fig. 7). According to her, the complementarity of the logical and the narrative rationality could prove extremely powerful for science education:

> Narratives develop […] a rationality that is not the logical rationality that science textbooks had included until now in their rhetoric. Including narratives in the science classes therefore implies introducing this new rationality, which […] is previous: it is vital and experiential. It is from this rationality that one should re-discover the advantages of objectivity, of the experimental method, of the construction of evidence from instruments that provide quantitative data… and that, in the end, generate the scientific entities that render the world around us […] understandable." (Izquierdo-Aymerich 2010, pp. 23–24, my translation)

The narratives used in 'Formaldehyde guests' intend to strike a balance between the two rationalities discussed by Izquierdo-Aymerich. Thus, a third, 'hybrid' rationality emerges, where abductive reasoning patterns are introduced. This kind of rationality could be identified in some of the most famous novels by Agatha Christie (Adúriz-Bravo 2003), and it would fit the model-based structure of the teachers' version of 'The landlady'. Such version retains most of the narrative character of the original tale while achieving a degree of law-based explanatory function more akin to a detective or forensic account.

Using these theoretical foundations, ten narratives were selected or constructed in order to work with science teachers along the unit; they are stories borrowed from other authors, adaptations, or materials purposefully created for the unit. The narratives are introduced in step 6 of the unit (see above), as epitomes of scientific activity for NOS analysis; they serve as vehicles both for the scientific and the historical information. As it was advanced, the narratives are mainly connected to the topics of structure of matter, atomic theory, and radioactivity (see Adúriz-Bravo 2005a, b, 2014; Adúriz-Bravo and Bonan 2006; Adúriz-Bravo and Izquierdo-Aymerich 2009). They include 'classic' episodes (e.g. Dalton's conception of the chemical atom, the Curies' work on radioactivity, Rutherford's proposal of a 'planetary' atom), more recent events (e.g. the 'radium girls', the bombing of Hiroshima, the nuclear accident in Goiânia), and fictional episodes (e.g. Godzilla, giant-sized Curies devastating Tokyo in 'The Simpsons', an episode on radioactive poisoning in the series 'House, M.D.').

For instance, the narrative 'The incredible case of the radioactive man' is the last one of the unit. It is presented orally by the instructors and complemented with a selection of newspaper clippings and technical information from the Chilean Commission of Nuclear Energy. It revolves around the so-declared 'radiological accident' that occurred in the Valley of Itata (Commune of Ránquil, Province of Ñuble, Region of Biobío), Chile, on the 14th and 15th of December of 2005.[2] In a cellulose plant under construction, worker Miguel Ángel Fuentes Oyarce got severely irradiated by a misplaced industrial source of iridium-192 for gammagraphy. Miguel Fuentes picked up and carried around the source for more than 10 min, with grave consequences for his health and the subsequent exposure of around 200 people (cf. Morales 2008). Fuentes was later sent for treatment to the Percy Military Hospital in France; he will have lifelong sequels from the 1,000-milisievert dose that he received.

With the narrative, the scientific content of radioactive poisoning is visited in order to introduce the NOS perspective. One of the key discussions with the teachers focuses on a note from the newspaper *Nación* (Alonso and Arriagada 2006) that calls the site of the accident the 'Chilean Springfield', and makes other references to 'The Simpsons'. The article is written in a heavily dramatic tone and includes scientific imprecisions and misrepresentations, which can be fruitfully examined with teachers using meta-theoretical concepts. On the one hand, notions such as scientific literacy, public understanding of science, and risk management can be applied to discuss the fact that it was only a foreign worker from another section of the plant who was able to indentify the true nature of the device that Miguel was carrying in his pocket. On the other hand, constructs such as scientific rhetoric, analogies and metaphors, and theory-ladenness provide the framework to assess diverse expert and folk interpretations of each step of the accident.

The NOS that teachers are expected to inspect with this narrative mainly refers to two of the aspects that constitute the 'mill':

1. *The nature of scientific observation* The notion of 'observability', when applied to a complex phenomenon such as radioactivity, makes a good case for the introduction of ideas such as the indispensability of instrument mediation in science and the unavoidability of theoretical interpretation of data.
2. *The nature of scientific explanation* The different 'explanations' that are (co-)constructed around Miguel's increasingly alarming symptoms of radiation burns and radioactive poisoning show the role that the explainers' models play in the process of explaining. According to the availability of more or less scientific models, explainers achieve different levels of success in relating seemingly unconnected data and drawing justified conclusions.

[2] For some information in English about the accident, see http://santiagotimes.cl/forestry-plant-workers-exposed-to-radioactivity/ and http://santiagotimes.cl/victim-of-radioactive-exposure-returns-to-chile/.

Concluding Remarks

Since the scientific narratives mentioned in this paper recur to historical materials, the didactical use of the history of science defended here should be briefly commented. The expression 'history of science' can have several meanings (see Kragh 1987, for classical distinctions):

1. The 'facts' that happened in science through time (acknowledging that we only access such 'facts' through the 'filter' provided by aims, expectations, culture, education, language, gender, age, ideology, etc.).
2. Any explicit, intentional, model-laden 'reading' of such facts performed from a distinctive theoretical positioning.
3. An academic discipline systematically investigating such facts and producing such readings.
4. Any different ways of *putting into text* the historical production derived from that discipline, which are subject to pragmatic and rhetorical constraints.

The theoretical ideas presented in this paper are mainly concerned with meaning 4, since what is here called 'science stories' are texts of narrative rationality (expanded with some elements of logical rationality) employed as the setting for philosophical discussion around NOS with science teachers.

But the construction of the narratives implies the need to resort to models, empirical results, reviews, constructs, and materials from the history of science *sensu stricto*, i.e. in meaning 3. Didacticians of science and as science teachers are *not* professional historians of science; therefore, they need to resort to work done by historians, especially those who are sympathetic to the issues and problems of science education. They then need to perform a didactical transposition on historians' work, giving priority to educational goals, even when this means introducing a certain amount of 'noise' in the process.

Since narratives that utilise elements from the history of science in sense 3 seem to be of the highest value in science teacher education, it follows as a conclusion the urgent need to develop criteria to *assess* the quality of the use that didactics of science makes of the discipline history of science.

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