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Teachers' Ideas About the Nature of Science: A Critical Analysis of Research Approaches and Their Contribution to Pedagogical Practice

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Abstract This paper looks into research aimed to elicit teachers' ideas about science through the development of resources as questionnaires, problematic tasks and interviews. It is focused on how those ideas are conceptualised and how such conceptualisations have been reflected in the methodological approaches adopted and the advantages and disadvantages of research instruments. This analysis suggests four broad categories to group studies considering substantially different perspectives on teachers' knowledge. Drawing upon the general finding that teachers tend to develop stereotypical views connected to science, there is an attempt to respond to the question of why such views are not sustainable from an educational point of view. A salient conclusion is that the large majority of such research remains marginal in informing pedagogical practice and faces serious conceptual and methodological challenges. It is also claimed that those studies adopting pedagogical embedded view of ideas about science do illuminate the way forward. The paper ends with a discussion on the implications of teachers' images of the world of science in their practice.

1 Introduction

Teachers inevitably convey messages about science in the classroom. Moreover, when such messages are expected to be explicit, teachers' ideas about science are likely to be reflected in their discourse and actions and may have influence on the extent to which students find science interesting, challenging and understandable (Zeidler and Lederman 1989). The ideas that teachers hold about the world of science have educational relevance because teachers deal with the important task of introducing science to young generations as one of the major intellectual human achievements. They are also relevant because they form part of a complex network of ideas interconnected to views on teaching and learning science. For instance, thinking that students can learn science by discovering things by

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themselves is consistent with the unsound idea that the outcomes of a single observation can be interpreted without any reference to a preceding conceptual framework. Ideas about science and associated pedagogical views may have a profound influence on the activities that teachers provide for students, how they organise and manage their classroom, what role they adopt, the way they use equipment and materials, and the criteria they use in assessing the success of work.

A world-wide interest in promoting the understanding of the nature of science in science education is evident in policy documents and curriculum guidelines, but also in the extensive research about teachers' and students' understanding about science. Particularly, teachers' understanding about science has been widely explored in the last decades. Researchers working in this area have used different terms, some of them being conceptions of the nature of science (e. g. Abd-El-Khalick and Lederman 2000), views of the nature of science (e.g. Nott and Wellington 1996; Zimmerman and Gilbert 1998) and epistemological beliefs (Sperandeo-Mineo 1999). These terms seem to be used to refer to well-bounded understandings that have little or no overlap with other areas of teachers' cognitive life.

I will argue that the large majority of such research remains marginal in informing pedagogical practice and faces serious conceptual and methodological challenges connected to much ambiguity on the nature of what is to be explored or 'assessed'. Exceptionally, there are also some studies which have adopted more insightful conceptual and methodological approaches to explore teachers' understanding about science and which illuminate the way forward. There is an impressive plethora of studies in the literature devoted to evaluate teachers' understanding about science in different countries and educational levels. Lederman et al. (1998) and Lederman (2007) offer comprehensive reviews of these studies. Studies in this field have generated a significant number of research instruments, the most prominent being questionnaires, situated probes and interviews with both quantitative and qualitative perspectives. Some of these studies are listed in Table 1.

This paper is aimed at fostering discussion on salient conceptual and methodological issues in this area. The points raised and discussed in detail are:

- Unrealistically, teachers' ideas about science are frequently expected to match perspectives developed in philosophy, history or sociology of science. Some normative criteria are always required to judge the adequacy of teachers' ideas. However, there is no single perspective that is adequate in all situations. There is a need to develop a flexible perspective that is philosophically informed and defensible, yet sensitive to the situation of teachers.
- There is a prevailing false assumption that teachers have a unique view of the nature of science that remains stable across contexts and can be articulated un-problematically.
- Findings allow little to be concluded on the pedagogical implications of teachers' ideas; when they are explored in a context vacuum or only in scientific content frames.
- Little research has been conducted to explore teachers' ideas about science in pedagogically relevant context and well delimited aspects about the world of science. The connection between teachers' thinking in this area and the actual demands they face in the classroom still requires more exploration.

A selection of studies reported in the literature is used to substantiate the points expressed above. Overall, research into teachers' understanding about the nature of science has evidenced that stereotypical ideas about science are common among teachers. After the critical analysis of research perspectives, I devote a section of this paper to consider the

Table 1 Some studies aimed to elicit and/or evaluate teachers' understanding about science

Study	Research instrument/strategy	Participants
Kimball (1968)	*Nature of Science Scale,* Likert scale type items	Pre-service teachers and undergraduate science students
Cotham and Smith (1981)	*Conceptions of Scientific Theories Test,* Likert scale items	Pre-service teachers, philosophy and science undergraduate students
Kouladis and Ogborn (1989)	Questionnaire (2 or 3 choices items)	Pre-service and beginning science teachers
Rampal (1992)	*Views about Science and Scientists Questionnaire,* open and close-ended questions	In-service secondary teachers
Pomeroy (1993)	Questionnaire, Likert scale items	Scientists, secondary science teachers and elementary teachers
Lakin and Wellington (1994)	Subject triads, repertory grids and follow-up interview	Elementary science teachers
Nott and Wellington (1995, 1996)	*Critical incidents* in group discussion and individual interviews	School teachers
Haidar (1999)	Questionnaire, bipolar close-ended items	Physics graduates and experienced teachers
Murcia and Schibeci (1999)	Questionnaire based on newspaper science report, open-ended and true/false questions	Pre-service primary teachers
Abd-El-Khalick (2001)	*Views of the Nature of Science Questionnaire,* general and specific open-ended questions	Pre-service Physics teachers
Lederman et al. (2002)	*Views of Nature of Science Questionnaire,* open-ended items and follow up interviews	Pre-service secondary teachers Expert and novice postgraduates
Cobern and Loving (2002)	Questionnaire, Likert-scale type items	Pre-service elementary teachers
Taylor and Dana (2003)	Think-aloud protocols based on tasks of experimental design and hypothetical classroom passages	Secondary teachers
Windschitl (2004)	Open empirical investigation task, journal records, interviews	Pre-service secondary teachers
Chen (2006)	*Views on Science and Education Questionnaire,* multiple choice items	Pre-service secondary science teachers
Irez (2006)	Interviews based on *Views of Nature of Science Questionnaire* questions	Pre-service science teacher educators
Liu and Lederman (2007)	Questionnaires on Worldviews and Nature of Science, open ended questions	Pre-service elementary teachers
Guerra et al. (2010)	Interviews based on pedagogical scenarios	In-service primary teachers
Buaraphan (2011)	Myths of Science Questionnaire, Likert scale items and justification of responses	Pre-service physics teachers

potential impact of stereotypical images of science on teaching practices. The final discussion intends to point out on the difficulties involved in the empirical exploration of teachers' ideas about the nature of science and the way forward to conduct studies which outcomes target to inform pedagogical practice.

2 Research into Teachers' Ideas About the Nature of Science Using Questionnaires and Interviews

In this section, I analyse first the features attributed, most of the time implicitly, to teachers' understanding about science in different research studies and how such assumed features are reflected in the methodological approach. That is, in the way that questions or probes are designed and the way teachers' responses are analysed and interpreted. Different but connected assumed features of ideas about science overlap in the studies. The outcomes, strength and limitations of the approaches are also considered.

The analysis of research approaches was motivated by my own need to develop a rationale to continue the empirical exploration of teachers' ideas about science in the context of science curriculum reform in Mexico (Guerra et al. 2010). Firstly, a search of literature was conducted to identify studies attempting to elicit and evaluate science teachers' conceptions through the development of instruments as questionnaires, problematic situations and interviews or a combination of them. Studies attempting to modify teachers' ideas about the nature of science were excluded in order to concentrate attention in the advantages and disadvantages of research tools. Given the diversity of instruments identified (close-ended and open-ended questions, normative and ideographic approaches, situated and non-situated perspectives, etc.); it was necessary to group studies sharing similar features. I ended up with four groups or broad categories emerging from a critical appraisal of literature on the field. Such analysis builts upon my experience of developing different types of questionnaires and interview schemes in educational contexts. The description of each category follows and it is illustrated with relevant sample questions and/or synthesis of the strategies in use.

2.1 Teachers' Understanding Expected to Match Academic Perspectives on the Nature of Science

It is not common at all that teachers have a strong background in philosophy, history or sociology of science. Such studies do not necessarily form part of their teacher education. However, possibly because of the need to have some solid normative criteria, many studies aimed to explore and elicit teachers' understanding about the nature of science have tended to compare teachers responses to academic perspectives, those that researchers agree with or those they want to contrast. In this way, what teachers should know is determined beforehand and sometimes even the 'right' response is established a priori. Methodologically, this approach has led to the development of numerous tests and scales. Such instruments have included different aspects of the nature of science and have varied in question formats. Despite controversies about their comprehensiveness and the interpretation of their outcomes, the development of test and scales in this area continues to attract much attention (e.g. Tairab 2001; Cobern and Loving 2002).

This exclusively philosophical normative approach, without sensitivity to the teaching context, can be illustrated with one of the first instruments designed especially for teachers. The 'Nature of Science Scale' (NOSS) developed by Kimball (1968) became widely used and influenced the development of others. The NOSS was based in what was called 'a theoretical model of science'. This model was formulated in statements expressing a particular perspective on the nature of science which was judged to have support in the writings of philosophers of science (Table 2).

The items of the NOSS were derived from such a model and constructed to confirm whether or not teachers' understanding agree with it. The NOSS was developed in the

Table 2 A theoretical model of the nature of science by Kimball (1968)

(1) The fundamental driving force in science is curiosity concerning the physical universe. It has no connections with outcomes, applications or uses aside from the generation of new understanding
(2) In the search for understanding, science is process-oriented; it is a dynamic, ongoing activity rather than a static accumulation of information
(3) In dealing with understanding as it is developed and manipulated, science aims at ever-increasing comprehensiveness and simplification, emphasizing mathematical language as the most precise and simplest mean of stating relationships
(4) There is no-one "scientific method" as often described in school science textbooks; rather, there are as many methods as there are practitioners
(5) The methods of science are characterized by a few attributes which are more in the realm of values than techniques. Among these traits of science are dependence upon sense experience, insistence on operational definitions recognition of the arbitrariness of definitions and schemes of classification or organization and the evaluation of scientific work in terms of reproducibility and the usefulness in furthering scientific enquiry
(6) A basic characteristic of science is a faith in the susceptibility of the physical universe to human ordering and understanding
(7) Science has a unique attribute of openness, both openness of mind, allowing for willingness to change opinion in the face of evidence and openness of the realm of investigation, unlimited by such factors as religion, politics, or geography
(8) Tentativeness and uncertainty mark all of science. Nothing is ever completely proven in science, and recognition of this fact is a guiding consideration of the discipline

tradition of psychometric procedures: validation by expert judges, pilot studies, item analysis and reliability tests. It consists of 29 statements with no references to any particular context which respondents were asked to 'agree', 'disagree' or chose a neutral response, like the following:

- Classification schemes are imposed upon nature by the scientist: they are not inherent in the materials classified. (Agree)
- Thanks to the discovery of the scientific method, new discoveries in science have begun to come faster. (Disagree)
- The ultimate goal of all science is to reduce observations and phenomena to a collection of mathematical relationships. (Agree)
- Team research is more productive than individual research. (Disagree)
- The essential test of a scientific theory is its ability to correctly predict future events. (Agree)
- If at some future date it is found that electricity does not consist of electrons, today's practices in designing electrical apparatus will have to be discarded. (Disagree)

The option in parenthesis refers to the correct answer suggested by Kimball's theoretical model of science. The NOSS was scored by assigning two points for each answer in agreement with the model, one point for a neutral response and no points for an answer in disagreement with the model. Respondents' scores ranged from 32 to 37 points out of 58, which was considered a poor performance. Scores obtained were regarded as a unitary measure of a person's understanding of the nature of science. Individual scores were used to make comparisons between large samples of pre-service teachers and undergraduate students. Little variability in scores was found among groups. Results suggested, not surprisingly, that teachers' responses did not fully match the 'right' pre-defined model of science and consequently that their understanding of science was 'less than satisfactory'. In his conclusions, Kimball argued for the introduction of more courses on history and philosophy of science in teacher education programmes. This claim for a more sophisticated philosophical knowledge base to teach about the nature of science was unrealistic in the short term and overlooked the fact that philosophical academic knowledge needs to be adjusted to the teaching context in order to be employed by school teachers and understood by the learner (cfr. Chevallard 1991).

Also using a philosophical normative approach, Kouladis and Ogborn (1989) described and compared 94 pre-service and beginning science teachers' views about scientific knowledge. They used the responses to 16 general multiple-choice items included in a larger questionnaire, addressing four main themes: (1) the existence and nature of scientific method, (2) criteria of demarcation of scientific from non-scientific thinking, (3) the existence and nature of patterns of growth of scientific knowledge and (4) the status of scientific knowledge. The following items exemplify each theme in the same order:

8) In general, the choice of the appropriate method to be used for a given problem:
a) is guided by a consensus of the scientific community
b) itself belongs within the concept of science
c) is made by individuals, using their own critical standards

11) The search for general rules for deciding between competing scientific theories or which one deserves to be called scientific;
a) is pointless because when theories change so do our ideas about how to decide between theories
b) is pointless because science merely persuades us to look at things in a certain way, which is no better than any other
c) is not pointless at all

16) Scientific knowledge:
a) has particular characteristics in that attempts to be an objective account of nature
b) has particular characteristics in that it is practically useful
c) has particular characteristics in that it is a systematic pattern of thought

There was an interest to identify trends among responses in agreement with a number of philosophical positions. For instance, a teacher choosing responses 15a and 16a but rejecting 15b, 16b and 16c could be identified as holding an inductivist view, but if he/she choose response 15b and rejects 15a and 16a could be considered to hold a relativist view. Based in their answers, teachers were classified into pre-defined categories (e.g. inductivism, hypothetico-deductivism, relativist-contextualism, rationalist-contextualism and relativism). Only two-thirds of the sample could be classified and most of the teachers were included in a version of contextualism. Although a third of participants seemed to hold mixed views and did not fit any category, it was assumed that teachers could show their understanding by agreeing or selecting general phrases without a need to explore their reasons for doing so.

One common aspect regarding analysis approaches in the studies of Kimball and Kouladis and Ogborn is that teachers' understanding about the nature of science is elicited in a way which only intends to check whether or not teachers' views resemble academic perspectives. The problem here is that teachers do not necessarily have opportunities to develop a deep understanding of the particular academic perspectives that researchers select, and their responses are unlikely to mirror them. The tendency to contrast teachers' ideas against an academic normative framework is accompanied by the loss of sensitivity to a range of legitimate ideas, which may or may not be defensible from a pedagogical perspective. Therefore, particular philosophical positions, abstractly stated, are taken as the proper yardstick with which to evaluate the adequacy of teachers' ideas about science instead of considering more pedagogically oriented criteria which could suggest which aspects of the nature of science teachers do not know but are relevant for their professional practice. Other common aspects shared by these studies are the close-ended (or 'tick box') type of questions and their de-contextualisation.

The main message coming from the studies reviewed in this section is that, generally speaking, teachers do not hold ideas about the nature of science that fully correspond to what are considered to be academically 'adequate views'. Rather, they hold eclectic or mixed views which do not mirror consistently a single particular view or a particular philosophical position. Considering that consensus is not the prevalent feature among academic scholars dealing with the nature of science, and that their perspectives are the product of scholarship during centuries, it is not strange that teachers who have not studied systematically such expert views on science do not consistently display them.

It is not difficult to perceive, however, why an instrument like the NOSS of Kimball or that one of Kouladis and Ogborn (1989) can be so appealing. They offer a relatively fast and efficient way to elicit teachers' understanding and are applicable to large samples. They also offer the possibility of obtaining numerical indicators which are supposed to reflect how much or how well teachers know about science. Such indicators allow comparisons among individuals and groups. But this type of instrument provides a very restricted look on teachers' understanding. Tests and scales can only give us a sense of how much teachers are influenced by or have been exposed to academic perspectives on the nature of science. The interpretation of the outcomes largely depends on the perspectives chosen by the developers and the criteria of 'adequacy' that they embrace. The latter is what Lederman et al. (1998) have criticised and called a biased interpretation of questionnaire outcomes. As a consequence, it should be questioned whether this kind of instrument provides a valid evaluation of teachers' ideas. Sometimes teachers who are perceived by researchers as having sophisticated and progressive views on the nature of science on the basis of their performance during interviews or teaching episodes, obtain unexpected negative or low results in the tests and scales and others who are supposed to have less 'adequate' understanding seem to get better scores (e.g. Bartholomew et al. 2004). This mismatch undermines the validity of the instruments.

The richness of the complex network of ideas that an individual may have concerning different aspects of the nature of science, obviously loses its meaning completely when reduced to scores or discreet responses. Teachers' ideas about science are much more complex than simply agreeing or selecting statements. The apparent advantages of using tests and scales can only be highly valued in a research perspective in which teachers' ideas about science are mainly an inventory of bits of information, applicable to any situation and in which pedagogical relevance is unnecessary to discuss; as they are transferred automatically to classroom practices. Not surprisingly, research findings have frequently portrayed a deficit view of teachers' knowledge, as suggested by Poulson (2001) in other subject related areas, emphasising teachers' apparent lack of knowledge and deducing that a better philosophical understanding of the nature of science would necessarily lead to better teaching. Such a deficit view, based exclusively on academic normative criteria, reflects a lack of distinction between knowing and doing: simply knowing more about academic perspectives on the nature of science is not necessarily a guarantee for better teaching about science. In Sections 2.3 and 2.4, I discuss other studies adopting more pedagogically situated scenarios to explore teachers' ideas about science and acknowledging the role of such ideas in teaching practices. Interestingly, such studies also arrive at a deficit view. That is, they also reveal that teachers' knowledge base regarding the nature of science tends, in general, to be narrow and simplistic. The big difference, as it will be argued, is that by adopting more pedagogically oriented criteria to judge the adequacy of teachers' ideas about science, those studies also reveal that, although infrequent, more functional and sometimes sophisticated views do feature among teachers' responses and are clearly linked to teaching practice.

Several studies aimed at assisting teachers to develop their understanding about the nature of science have adopted tests and scales with academic normative perspectives (e.g. Sharmann and Harris 1992; Palmquist and Findley 1997; Mellado 1997). The interventions have taken the form of general courses and specific training within initial or in-service education programmes, which have openly included elements of philosophy and history of science or implicitly assumed that teachers' views of the nature of science would change as a by-product of strengthening content knowledge and engagement in scientific enquiry activities. The uses of instruments that expect teachers' understanding to match academic perspectives have led to some uncertainty on the effectiveness of interventions. This is because the features of training in this area has not been focused only on academic knowledge about the nature of science, which is what the instruments evaluate, and other 'improvements' in teachers' understanding escape their scope.

2.2 Teachers' Understanding About Science as Articulated and Stable Knowledge

Other feature implicitly attributed to teachers' ideas about science is that when elicited, they are already articulated and can be easily expressed. It follows then that teachers should not struggle to put their ideas into words. Consequently, teachers are frequently expected to display un-problematically what they know about science in their responses to direct questions with no preamble. In several studies into teachers' understanding about science, there is also a prevailing false assumption that the understanding about science that a teacher holds, constitutes a unique and somehow general view which remains stable across different contexts. Based on this, many studies have involved the use of general and abstract questions to which teachers can also respond in general terms. Even when teachers refer to a particular setting, their ideas are taken as stable and transferable to any other possible context.

A case in which teachers' ideas are conceived as articulated and stable knowledge is that of Rampal (1992). She developed a questionnaire called 'Views about Science and Scientists', or VVV by its initials in Hindi, which was completed by 199 teachers either attending or assisting training in a summer science teaching programme. The questionnaire included questions with no context. This instrument combined 8 open-ended and 22 multiple choice questions, which illustrative examples are:

(1) Have you ever met a scientist?

(2) If so, give a brief introduction and describe the area of work of the scientist.

(9) It is said that scientists possess a "scientific temperament" which clearly… ( )
a. Reflects in everything about them
b. Shows while they work in the laboratory
c. Reflects in their social behaviour too
d. Does not reflect in every aspect of their life

(26) It is said that science is the search for truth and scientist believe only in facts. In your opinion, while collecting or presenting information scientists… ( )
a. Are never influenced by governmental pressure
b. Never distort data for personal gain
c. Do, however unconsciously, get influenced by social biases
d. Do not always function in an unbiased manner

The open-ended questions directly required teachers to frame their understanding in written words. Results suggested that from 85 to 90% of teachers claimed to have never met a scientist. Those with affirmative responses associated to scientists qualities of 'discovery' and 'sharp thinking' although there were a variety of perceptions of who a scientist could be. For instance, an ingenious mechanic, a housewife in a well-organised kitchen, a science school student and a university professor were regarded as scientists. As teachers did not have an opportunity to articulate ideas, there was a possibility that they improvised some responses or expressed the first thing that came to their mind. Responses to close-ended questions, posed in general terms, contributed to delineate a strong stereotypical view of scientists. No attention was given to potential distinctions among who a scientist could be in a professional setting or elsewhere, leaving behind the diverse connotation of the word 'scientist' in teachers' responses. The fact that terms frequently used in questionnaires may mean for teachers something different from what researchers believe is evident in the responses to the VVV. There, the view of a mechanic, a housewife or a student as lay-scientists that comes from teachers' responses to open-ended questions clearly contrasts with the more professional image that the researcher seems to suggest in multiple choice questions. Although all questions used by Rampal were de-contextualised, the open-ended ones allowed teachers to express some particularities of their ideas.

Another case, in which teachers are expected to hold articulated and stable knowledge about science, is evident in the multiple efforts to develop the 'Views of the Nature of Science Questionnaire' (VNOS) by Lederman and colleagues (Lederman 1999; Abd-El-Khalick 2001; Lederman et al. 2002). Several versions of the questionnaire have been trialled and responded by different groups including high school students, undergraduates, postgraduates, elementary and secondary teachers. I focus here only on the reported experience of using this questionnaire with elementary pre-service teachers (Abd-El-Khalick 2001) before a pre-service physics course which effects on teachers' views of the nature of science were to be evaluated. The version used in such occasion included eight direct open ended items, six general questions with no particular context and two which were content specific, that is with reference to a scientific topic (the structure of the atom and the extinction of dinosaurs). The following examples are offered to illustrate the kind of questions considered:

1. What in your view, is science? What makes science (or a scientific discipline) such as physics, biology, etc. different from other disciplines of enquiry (e.g. religion, philosophy)?

3. Does the development of scientific theories require experiments?

5. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.

6. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?

A qualitative and interpretative analysis was conducted on written responses in search for patterns or categories. The predominant view was called 'scientistic', as scientific knowledge was generally thought to be true, proved and uncontested knowledge reached through neutral and objective observations of natural phenomena and by following a universal scientific method. In a view of science in which 'seeing is knowing', teachers generally did not express recognition of the inferential and theory-laden features of scientific constructs and claims. Asked to write explicitly about the difference between scientific laws and theories, not surprisingly, teachers did not manage to express well articulated and consistent views. With no particular examples at hand, teachers appeared to conceive theories, not as evidence-based explanatory systems, but as 'guesses' advanced for empirical testing. Responses to the item regarding the structure of the atom suggested that the majority of teachers thought that scientists can be sure of its structure because they have seen atoms under the microscope; revealing a non-distinction between inferences and observation. The predominant view for teachers was that objectiveness was the main thing involved in scientists' work, where creativity and imagination had little or no role to play. The findings suggested that most participants held a naïve perspective of science. Here, the assumption was that teachers could or should match the characterisation of science as tentative, empirical, theory-laden, inferential, imaginative and creative which is, as Lederman et al. suggest, highly informed by philosophical perspectives. This is again a normative approach followed this time in the analysis of open-ended responses.

The common aspect in the studies of Rampal and Abd-El-Khalick that I want to highlight is that teachers are expected to provide well articulated responses on issues that they might have never considered previously. The assumption is that teachers should be able to express their ideas without difficulties. This does not leave any opportunities for teachers to articulate their ideas, to justify and elaborate them. This does not mean that if teachers are given time to reflect and discuss their responses (e. g. with a colleague) before completing the written questionnaire, they would necessarily provide more sophisticated responses. From a methodological point of view, the inherent problems of the instruments in which teachers are expected to articulate responses on the spot and in writing, is that the researcher ends up trying to make sense of partially framed texts which have to be taken at face value and that there is no place for exploring teachers' ideas in more depth.

Another methodological issue coming from these studies and many others using decontextualised and direct questions (e.g. Pomeroy 1993, Haidar 1999) is the common approach to asking questions in a contextual vacuum. The lack of context in questions makes difficult to gain insights on the instances that respondents may have in mind when answering a particular item. For instance, in the VNOS it is difficult to know what a teacher recalls when reading terms as 'theory', 'law', 'experiment' or even 'scientist'. It is assumed that both respondents and researchers perceived the same meanings in the wording of questionnaire items and provided answers. Munby (1982) has called this the 'doctrine of immaculate perception'. More recently, Irez (2006) explored ideas about the nature of science of pre-service science teacher educators; using the VNOS questions administered as interviews and concept maps to analyse responses. Not surprisingly, the majority of participants were found to hold various inadequate conceptions regarding the nature of science given their lack of previous interest and reflection on the topic. Although Irez recognizes that participants had to face complex questions in the spot, their responses were treated, once again, as knowledge that is stable and transferable to any other possible context. Another study with the same research perspective was that of Liu and Lederman (2007), who explored simultaneously teachers' ideas about the nature of science and worldviews, taking into account the non-western cultural background of participants. An adapted version of VNOS questions were used in addition to open-ended questions about human-nature relationship. Responses to nature of science questions were again treated as stable knowledge with no reference to teaching science practices and classified into naive and informed responses. This approach continues to prevail in Buaraphan's (2011) recent effort to develop another questionnaires based on McComas' (1998) nature of science myths.

Studies exploring teachers' ideas about science which appear to assume that 'it is easy to say it' and 'context doesn't matter' do have some advantages over tests and scales. Teachers are allowed to express whatever they have to say regarding the question, the interest is shifted from agreement with normative criteria to the actual content of teachers' responses and the identification of features or patterns. However this type of study is still limited to provide insights on their diversity and richness, as no time is given for teachers to articulate their ideas and no attention is given to the specific settings that teachers have in mind while responding questions. The idiosyncratic ideas about science of teachers revealed by these studies suggest again the frequent deficit view but discussion on the relevance of such ideas for classroom practice are absent.

2.3 The Topic Matters: Teachers' Understanding About Science as Knowledge Contextualised in Science Content

Attention can now be drawn to another kind of study embodying the recognition that teachers may apply different ideas in different contexts, instead of holding a stable and articulated view to be applied systematically in all situations. I refer to studies exploring teachers' ideas about science in the context of specific scientific or science related topics. In these studies, teachers' understanding is explored through questions or probes delimited in a specific instance of scientific knowledge. In this way, there is common context, fairly defined, that all participants share. When it comes to interpretation, this allows much more certainty on what teachers take into account when responding to specific questions.

For instance Cotham and Smith (1981) designed an instrument called Conceptions of Scientific Theories Test (COST) including Likert scale items prefaced with brief descriptions of a theory and episodes drawn from its history. As the name of the test suggests, it was focused on aspects regarding scientific theories: ontological implications, their testing, generation and choice among competing theories, each aspect corresponding to a subscale in the questionnaire. Four different contexts were used: Bohr's theory of the atom, Darwin's theory of evolution, Oparin's theory of abiogenesis (formation of the simplest forms of life from primordial chemicals) and the theory of plate tectonics. Paragraphs describing the context were followed by items like:

Plate tectonics is a new theory. Given enough time it's likely that enough evidence will be accumulated to prove it conclusively.

Strongly agree	Agree	Disagree	Strongly disagree
(1)	(2)	(3)	(4)

A strong contextualisation like in the former item and in the general design of research probes allows the delimitation of the terrain in terms of scientific content. However, in this case, the close-ended questions combined again with normative criteria, prevented teachers from expressing their reasons for choosing a particular response in a given context. The scores in the subscales were intended to allow the classification of teachers by conception of science (instrumentalist vs. realist; conclusive vs. tentative; inductive vs. inventive; objective vs. subjective). Whether teachers believe that a theory could be proved on the basis of accumulated evidence, or be regarded as better than another one, depends on the specific theory in question. The different ideas that teachers could apply in each theory context could have been traced. Unfortunately, the reported experience is centred more in the procedure to obtain evidence in support of the reliability and validity of the instrument through traditional statistical procedures than in a characterisation of participants' views and their consistency or inconsistency across different contexts. Not surprisingly, the results suggested that philosophy and science students hold more sophisticated conceptions of theory testing, theory generation and theory choice than teachers.

Another study in which researchers included questions framed in a particular science related context is the study reported by Murcia and Schibeci (1999). They investigated 73 pre-service primary teachers' views of the nature of science and evaluate the use of newspaper science reports as part of a procedure to elicit their views. The text of the report was presented as a stimulus for teachers to articulate their views and afterwards they were asked to write down answers to several questions (Table 3). The underlying assumption in this study was that an understanding of the nature of science affects the ability to comprehend, interpret and evaluate claim based on scientific research. Responses to the probe were analysed in a qualitative manner, searching for similarities and differences among responses and putting emphasis on the content of what teachers wrote.

Teachers noticed the limited information provided in the newspaper. However there was minimal evidence to suggest that teachers could critically question the report. An important proportion of answers reflecting a view of science aimed to discover knowledge about the world and as a static set of facts to be learned led researchers to conclude that teachers hold a relatively limited understanding of the nature of science. Evidently the newspaper article served as a common topic context for all participants and most of the questions referred to it, making less uncertain what teachers had in mind while expressing their ideas. While this study's approach moves towards an interpretative description of teachers' understanding about the nature of science, the lack of other topic framed questions did not allow comparing ideas across contexts. How the capacity of teachers to critically question media reports, based on their understanding of the nature of science, was linked to teaching about science remained non-discussed.

So far, I have tried to point out that a research interest in teachers' understanding of science does not benefit much from assuming that such understanding must match academic perspectives, it is easily articulated and stable across contexts. The recognition that different ideas can be applied in different situations, and therefore that the context matters, have led to more responsive methodological approaches but they still do not necessarily guarantee more insightful interpretation of what teachers understand about science.

Table 3 A contextualised probe used by Murcia and Schibeci (1999)

Healthy tipple

People who enjoy the occasional drink may be doing more harm to their health than regular drinkers, a Newcastle University study shows. Researchers found a couple of drinks each day was likely to prevent a heart attack. But those who indulged in alcohol once in a while were more likely to suffer serious illness or die. The 10 year study, published in the British Medical Journal, also warned binge drinking was far more of a health risk than regular moderate consumption. It looked at 11,500 cases of people who had suffered heart attacks and 6,000 who had not (Western Australian Newspaper, 19 April 1997)

(1) In this article, what was the researchers' conclusion? And, do you agree with it? Why or why not?

(2) What do you think is the purpose of research of this kind?

(3) The article is about one kind of science. What do you think is the purpose of science generally?

(4) How do you think the scientific results discussed in this article were produced? That is, What procedures were used in this research?

(5) The article states, *Those who indulged in alcohol once in a while were more likely to suffer serious illness or die*. Do you think this statement is a scientific fact? Explain your answer

(6) Do you think creativity plays a role in science? Explain why you think it does or it doesn't

(7) What do you mean by the term *science*? Explain in your own words

I perceived here a divorce among the features implicitly attributed to teachers' understanding, the design of questions (research tools) and the interpretation of teachers' responses. There is a need for more integrity among these elements. Conceptual clarity regarding what is being researched, an ensuing methodological approach and a sound consequent interpretation are unfortunately not so common in studies aimed to elicit and evaluate teachers' understanding about the nature of science.

Although this analysis of literature is limited to teachers' understanding explored through questionnaires, qualitative probes and interviews, it is necessary to mention a study on students' understanding about the nature of science using content- framed tasks, which has been influential to develop awareness of several conceptual-methodological issues. In a cross-sectional study, Driver et al. (1996) explored school students' (aged 9–16) understanding of the nature of science. The development of highly content-framed tasks, similar to school learning activities, built upon the very explicit position that students' understanding about the nature of science is context-dependent, and implicit in their reasons for taking particular actions. They pointed that the distinction between espoused views, those declared, and views implicit in action was an important one. The adopted approach for analysing students' ideas intended to characterise them within the students' perspective and without reference to philosophical normative criteria. More than judging whether students' ideas about science were 'adequate' or not, Driver and colleagues were interested in identifying features of epistemological reasoning reflected in students' responses. A major outcome of this study was an analytical framework which includes three qualitative distinct forms of reasoning (phenomenon-based, relation-based and model based) which serve to describe how scientific enquiry, knowledge and the relationship between theory and evidence are represented in students' discourse. It was acknowledged that the forms of reasoning do not portray trends at an individual, but at a collective level and that the use of different representations could be suitable in different science content contexts. The type of probes they used overcomes the uncertainties associated with the lack of context that has undermined data from so many previous studies. The ideographic approach adopted in the analysis of students' responses—that is, making sense of students ideas in their own terms rather than judging them against pre-specified categories—differs substantially from the limited evaluative perspective that has prevailed in so many studies exploring students' and teachers' ideas. This is an example of the integrity among an explicit conceptual perspective, methodological approach and interpretation that I referred to earlier.

Back to the studies aimed to explore teachers' ideas which take into account particular contexts, like Cotham and Smith (1981) and Murcia and Schibeci (1999); they seem to offer more potential opportunities to obtain richer data with contextualised items and stimulus material. When open-ended probes are used, the added advantages are the possibilities of avoiding restricting teachers' responses to limited options and a gain in sensitivity to a range of possible ideas in content framed situations. Although there is much more space for description and interpretation of teachers' responses, it is not always exploited, possibly because there is still no account on how the ideas under analysis are linked, or could be linked to teaching. That is, when teachers' ideas about science are explored in a particular scientific content context; if such context is only subject-framed, the findings allow little to be concluded on the implications of teachers' ideas on their pedagogical practice. This shortcoming prevails even in the proposal of Chen (2006) to continue developing a close-ended instrument (Views on Science and Teaching Questionnaire). Such instrument is a likert scale 102 item questionare incorporating aspects of the nature of science and relevant teaching attitudes. Despite the fact that items were generated from teachers' point of view explored first as open-ended reponses; the profile of ideas remains limited to those selected by the questionnaire developer. Consequently, the instrument can not cover the complex and intricate relations between ideas about science and ideas about teaching nature of science aspects.

2.4 Teachers' Understanding About Science as Knowledge Contextualised in Pedagogical Situations

Relatively few studies have explored teachers' ideas expressed in educationally relevant situations. There, it is recognition that teachers' ideas about science are part of a complex network of functional knowledge interconnected with views about what is involved in teaching and learning science and embodied in pedagogical action. Consequently, studies with this perspective have introduced the use of questions framed in classroom settings and tasks contextualised in situations that teachers are likely to experience and link to their professional practice.

For instance, Nott and Wellington (1995, 1996) endorsed a methodology based on what they called 'critical incidents' to probe teachers understanding about science. They defined a critical incident as an event, qualitatively described and rooted in classroom experience, which makes a teacher decide on the course of action and involves some kind of account of the scientific enterprise; for instance events like practical work going wrong in the classroom or episodes that raise questions about scientific knowledge or the conduct of scientists. Critical incidents were intended to evoke responses from the teacher which provide an insight into the teacher's ideas about the nature of science as well as matters to do with teaching and learning. Examples are offered here to illustrate the type of episodes called critical incidents:

- Below, there are two episodes from lessons.
  1. A teacher is doing the starch test on leaves. For inexplicable reasons the tests are indecisive.
  2. A teacher is demonstrating the non-magnetic properties of iron sulphide. However the freshly made sample sticks to the magnet.
  In both cases pupils say the following: But science experiments never work. Anyway, we'll believe you, if you tell us the result.
  List the kind of things you could say and do at this point.
- You have a particularly reluctant learner in your Year 10 class. The pupil is not aggressive but assertive that this work on chemistry is not something s/he likes doing. When you ask why the pupil says: Because if it hadn't been for chemists, we wouldn't have these chemicals ruining the Earth.
  List the kind of things you could say and do at this point.

Nott and Wellington used critical incidents in group discussions and as stimulus in one to one interviews with teachers. Their analysis of responses focused on the messages about science that teachers may convey, the pedagogical strategies they recalled and the opportunities to teach about science that teachers perceived in the critical incidents. Salient aspects of teachers' responses were their diversity and the display of the 'practical wisdom rather than academic knowledge', but several trends were identified. In responses to critical incidents in which practical work goes wrong, teachers tended to suggest that they would deceptively produce the correct 'matter of fact' on the spot or, beforehand, they would draw upon their knowledge and experience to ensure that apparatus and procedures work (like using devices with certain specifications or having alternative resources at hand). Other teachers suggested in their responses that they would engage students and themselves in critically evaluating the design and materials involved in activities. Those teachers, according to their responses, were more likely to convey messages about school science as an activity were empirical work should be preceded by 'ideas in your head before you start', needs to be evaluated and repeated; produces results that have to be shared, negotiated and collectively criticised; and that when things 'go wrong', there is a rational explanation. In responses to non-practical critical incidents, some teachers perceived opportunities to discuss issues like experimentation with animals, scientific explanation as an alternative to other forms of knowing, the social commitment of scientists and the advantages and disadvantages of the application of scientific knowledge.

It is evident that this type of pedagogically contextualised probes can unravel aspects of teachers' understanding of science that tests and scales can not. They allow describing a range of ideas about the nature of science implicit in teachers' responses and formulating hypotheses on how they might figure in teachers' classroom discourse and actions. Nott and Wellington acknowledge the distinction between knowing and doing, that is, in real teaching situations teachers might not do what they say they would do; simply because classroom life is complex and other factors are involved (e.g. limited teaching time, syllabus constraints, skills to manage discussions). A limitation of critical incidents, for a more general application, is that they need to be genuinely possible in teachers' school culture. The critical incidents described by Nott and Wellington, for instance, would hardly occur in the context of Mexican primary science because no science laboratories exist and practical work is conducted in more rudimentary conditions. As teachers' ideas about science are strongly bounded to the specific situations in which they are explored, there are certain limits for generalisations. Nott and Wellington (1996) have argued that different groups, teachers among them, have different perceptions of science and such perceptions are also grounded in their shared practices and cultural setting. Nevertheless the advantage here is the possibility of some access to a body of functional knowledge in more authentic scenarios. From a research point of view, this seems to me a more fruitful perspective than the more frequent de-contextualised approach to exploring teachers' ideas about science. It allows us to make inferences about teachers' thinking from their responses about pedagogical actions rather than espoused general views in response to de-contextualised questions.

A second case of a pedagogically framed study is of Taylor and Dana (2003). Taking into account both content and pedagogical contexts, they report a multiple case study focused on three secondary teachers' conceptions of scientific evidence; specifically in connection to measurement reliability and experimental validity issues. They used think-aloud protocols based on tasks contextualised in both electricity and mechanics topics. Teachers were asked to design one experiment in each context to investigate: (a) the relationship between a wire's length and its resistance, and (b) the relationship between the weight of a wood block and the minimum force required to pull it up a slope; or (c) the relationship between the angle of the slope and the minimum force to pull a block up the plane. Teachers were required to explain their rationale in designing the experiments in a particular way. Besides that, teachers had to comment on hypothetical classroom passages containing the same experiments but designed by students and their corresponding results and conclusions. Responses were qualitatively analysed in search of recurring regularities and common themes. Taylor and Dana's found that to judge experiments and data generated by students, teachers integrate conceptions of measurement validity with specific subject knowledge relevant to the experimental design. In some cases such integration was critical to allow them to recognise the relevant variables but not in others. Teachers tended to equate little or no variance in data with reliability and valid experimental designs, sometimes regardless if all relevant variables were properly controlled. Findings also suggested that the teachers could recognise the purpose of controlled experiments, identified relevant variables but not necessarily controlled them in their own experimental designs. Teachers were much better at recognising flaws in students' experimental designs and collected data than in their own designs and data.

In Taylor and Dana's study, it is possible to appreciate again a functional view of teachers' knowledge and an interest in the ideas about science implicit in teachers' responses. The focus is not in abstract notions of measurement reliability and experimental validity but in their understanding of the issues in concrete situations which are likely to be faced by them and their students. The pedagogical relevance of teachers' understanding is clear. Whether teachers understand or not the issues matters because they are connected with how they assess students' performance and the feedback they can provide. Due to the specificity of the scenarios used, it is difficult to assume that teachers would respond similarly in other situations. The approach used by Taylor and Dana suggests that teachers' understanding of certain issues of the nature of science elicited in authentic scenarios is complex and does play a potential role in teaching.

More recently, Windschitl (2004) explored how 14 pre-service secondary teachers conceptualise scientific enquiry and if those ideas were translated into classroom practice. As part of their science method course, teachers were asked to identify a question in a scientific topic, and then design their own empirical investigation which involved collection and analysis of data and then presenting and defending their results in front of colleagues. Eight weeks were given to conduct their investigations. They kept a journal in order to have a record of procedures, thoughts and feelings generated during that time, but also were asked to write on how the experience informed their considerations to conduct enquiry experiences with their future students. During the course, teachers had opportunities to discuss the use of enquiry activities in the classroom and their ongoing investigations in small groups. Such discussions tended to focus on the difficulties in generating 'researchable' questions, to obtain and use equipment and to collect and process data. After teachers presented their results, they were interviewed about their experience with scientific enquiry in their formal education and professional careers, and the implications of their experience during the course for using enquiry activities with students in the future. Finally, teachers were observed in their teaching practices at school settings to monitor their use of enquiry instruction.

Contrary to what they initially thought, most participants found great difficulty in the planning and realisation of an independent enquiry; even those with substantial science background, to the point that some suggested that independent enquiry was impossible with students. They encountered problems in operationalising variables, controlling them, securing equipment, defining procedures to gather data, etc. Windschitl identified in diaries and interview transcripts several dimensions of what he called a 'folk theory' of scientific enquiry which combine elements that were considered congruent with authentic science enquiry (e.g. logistical and methodological setbacks are to be expected and some times results can be inconclusive), with a limited view of scientific enquiry (e.g. differences among experimental conditions can be established without considering statistical significance) or with misrepresentations of fundamental aspects of scientific enquiry (e. g. explanatory frameworks and models are optional and not necessarily required to conceive an investigation and to interpret results).The notion of a 'scientific method' as an atheoretical approach to scientific enquiry was predominant among participants.

Windschitl comments that the idea of a self-contained procedure which does not need to be connected to theories or models, with orderly steps and epistemological complexities ignored is, for teachers a very useful fiction; as well-defined activities conducted in a highly prescriptive style is the easiest and most manageable form of enquiry with large groups of students. The situation is complex as teachers' ideas are not simply right or wrong. The 'folk theory' combines defensible and not defensible ideas about scientific enquiry from a pedagogical point of view. In that sense, it is not necessarily convenient that teachers have useful fictions just because such ideas are helpful to justify some practices. Although functional, Windschitl suggest that the atheoretical and stepwise notion of scientific enquiry is counter-productive as it reflects and perpetuates an undesirable and artificial separation of activities with investigative purposes and conceptual framework in school science.

Only those teachers with significant previous research experiences, as undergraduates or professionals, tended to use enquiry activities in the classroom in a more confident and systematic way. Being involved in authentic scientific investigations in non-school contexts apparently provided insights and positive attitudes towards enquiry at school. The most salient ideas that teachers registered as implications for doing enquiry were to give students direct instructions on procedures and skills to use; adding structure to the enquiry process by restricting the number of topics for enquiry, providing already made research questions and approval from the teachers over students' enquiry plans. Providing background content was almost never mentioned.

This type of study offers a high descriptive and interpretative potential. It focuses attention on the diversity and qualities of teachers' responses and their meaning in teaching related situations. Kagan (1990) has introduced the notion of ecological validity. It refers to the kind of evidence researchers provide concerning the relevance of a specific methodological technique to classroom life. In this sense, the type of probes used by Nott and Wellington, Taylor and Dana, and Windschitl are ecologically valid as they reflect more authentic situations where teachers are likely to apply their ideas about science. This approach allows having common tasks for groups of teachers, and the researcher can control to some extent the issues to be focused on. A possible limitation, however, is that the use of pedagogically embedded probes relies heavily on tasks or descriptions where specific details become crucial. The possibilities of using such probes with other groups of teachers or of generalising results are limited. Despite the fact that probes are more authentic and related to teaching and learning science, there is still an obvious distance between probes and real classroom situations. Perhaps a major contribution is the possibility of making inferences on the links between teachers' ideas and pedagogical action amenable of further empirical study. Some criteria are always required in order to judge the adequacy of teachers' ideas for teaching purposes. The last three studies show how a more pedagogically embedded judgement on teachers' knowledge can be adopted. Since I consider this perspective to be the most fruitful and promising, there is an effort to apply it in the study of teachers' ideas about science through questionnaires and semi-structured interviews based on pedagogically relevant contexts (Guerra et al. 2010).

In this section, I have analysed some studies and identified different perspectives in which particular features are implicitly attributed to teachers' understanding of science. I commented on their strengths and limitations from conceptual and methodological points of view. It has been noticed that methods for probing students' understanding on aspects of the nature of science make assumptions about the nature of human knowledge and understanding and that such assumptions may or may not be explicit (Leach et al. 2000). From the analysis done in this section, it is clear that this observation is also applicable to the range of methods used to elicit teachers' understanding. It is noticeable that researchers interested in teachers' understanding of the nature of science have employed diverse methods to collect data. Originally focused on the development of standardised instruments, research in this field seems to be adopting more qualitative, open-ended approaches.Teachers' understanding of the nature of science has been explored with diverse research tools. Only questionnaires, problematic situations and interviews are considered in this paper. It would be difficult to argue that some methods are simply better than others. Obviously, their adequacy depends on the research aims, focus and perspective. However there is some evidence suggesting that in order to access teachers' ideas about aspects of the nature of science open-ended approaches are more sensitive to the complex web of ideas that teachers' understanding about science can be. Rationales about the role of such understanding in teaching science, clear and explicit accounts about the nature of the understanding to be explored and focus on particular but relevant aspects in the contexts of pedagogical practices are, for the analysis of research data, highly relevant.

The main finding from studies aimed to elicit and evaluate teachers' understanding of the nature of science is that, generally speaking, they hold eclectic or mixed views which do not mirror consistently a single particular view or a particular philosophical position. Their understanding seems to be much more complex than simply agreeing or selecting abstract statements. Teachers do not hold very often what researchers expect to be adequate views about the nature of science. This is not surprising due to the tendency to judge teachers' ideas against abstract philosophical statements. Efforts to qualify rather than quantify ideas about science are promising. Another message coming strongly from research in this area is the predominance of stereotypical images on diverse aspects of the world of science over other more diversified views. Such stereotypical images tend to be tacit are rarely scrutinised or questioned by teachers. Since such stereotypical images are so pervasive, a discussion on their implications is offered in the next section. The deficit view of teachers' ideas about the nature of science continues to arise regardless of the approach to analyse their responses. A major contribution of studies adopting a situated perspective and pedagogical criteria informed by the contributions of philosophers, historians and sociologists of science to judge the performance of teachers, is that they can provide an account on how both limited and sophisticated ideas about science can be related to teaching practices.

3 Stereotypical Images of Science: Why They Are Not Sustainable

In this section I come back to the atheoretical 'folk-theory' of scientific enquiry (Windschitl 2004), the 'scientistic' view of scientific knowledge (Abd-El-Khalick 2001); and the conception of the 'unfamiliar yet extraordinary' scientists (Rampal 1992) documented in studies considered in the previous section. Stereotypes, as oversimplified ideas of the characteristics which typify a person or a thing, may play a role in human understanding by abstracting or abridging complex issues and providing quick references. But stereotypes related to science and held by teachers are, in the best case, double-edged swords for teaching practice. They also maintain very limited perspectives on substantial aspects of the world of science. Leaving them unquestioned becomes an obstacle to acknowledging that things can be richer and more complex. Research into teachers' understanding about the nature of science has established that stereotypes are spread among teachers. There is probably no more need to show their existence but a need rather to consider their potential impact on teaching practices in school science. The following discussion is centred in why stereotypes do not stand scrutiny from a pedagogical point of view.

3.1 The Atheoretical 'Folk Theory' of Scientific Enquiry

Windschitl (2004) has suggested that the notion that there is a linear and universal procedure to be followed in scientific research is common among teachers and has become a counter-productive 'useful fiction'. He argues that a self contained procedure with orderly stages which does not need to be connected to theories or models is the best functional simplification that allows teachers to accommodate their practices to the low cognitive demand and the prescriptive style that predominate in the science classroom. Sometimes the 'method' is exemplified in activities which do not involve previous planning, a clear purpose, or where the outcomes take a second place after the procedure itself. Other situations seem to contribute to sustain such a stereotypical view of scientific enquiry. The enumeration of sequential steps to follow in scientific work is common place in textbooks and usually includes: defining a problem, gathering background information, forming a hypothesis, making observations or experiments, testing the hypothesis, and framing conclusions (Abell 1989; McComas 1998).

From a pedagogical point of view, the notion of an atheoretical, linear and universal method can only encourage a very restricted view of science itself and carries out other ideas about science and the practices of scientists. Conceived as a procedural straightforward pathway to scientific knowledge, valid in any situation regardless on what is to be researched and what for, the attention focuses on the action rather than the purpose and ideas. This, Millar (1989) suggests, shifts the emphasis from scientific knowledge as reliable knowledge towards scientists as reliable knowers. In the logic of the stereotype, as one single procedure is valid in any situation, the scientific method is the distinguishing feature of science itself. The recognition of different methodological approaches in different scientific disciplines by different people and for different purposes becomes difficult. Scientific enquiry in the classroom takes the form of practical work. Teachers are not always aware that 'doing science' in the classroom is most of the times a teaching resource more than an accurate depiction of what an investigation is like in professional science (Osborne 2002). Subtly but pervasively, science education rhetoric for teachers promotes the idea that scientific enquiry is simultaneously a teaching strategy, an opportunity to develop students' investigative skills and as a window to the practice of professional scientists.

The stereotypical view of scientific enquiry can be challenged by a brief consideration of different academic perspectives on scientific methodology (O'Hear 1989; Chalmers 1997 and Okasha 2002). For centuries, philosophers have reflected on the methods of science and have discussed whether observation and induction, deduction or mathematical modelling, to mention some, could be regarded as the distinctive method of science. By the middle 1970s, Paul Feyerabend proposed what came to be known as 'epistemological anarchism', defending that there is not such a thing as scientific method and the provocative idea that in scientific enquiry 'anything goes'. My point here is that perspectives among scholars reflect also diversity rather than a unitarian view of science.

Efforts to overcome the stereotype of scientific enquiry would involve some acknowledgement that it is extremely simplistic to conceive one single science having a unitary method. Consequently, teachers may need some explicit awareness, for instance, that in the over-specialised modern practices of science, scientists are not always involved in observation and experimentation but in modelling and theorisation. Developments in instrument making, in mathematics and statistics, in terminology and communication technology have altered the methods used in science. Moving from the assumption that the simplistic stepwise 'doing science' in the classroom reflects scientific activity as practised by scientists, to talking explicitly about what is involved in scientists' work is challenging. Research suggests (e.g. Taylor and Dana 2003) that, generally speaking, teachers are unlikely to be equipped to draw on specific cases to exemplify different strategies used to conduct scientific work and to connect them some considerations about the quality of information, the validity of claims and interpretations in key curriculum contexts.

3.2 The 'Scientistic' View of Scientific Knowledge

In the study by Abd-El-Khalick (2001), the emergent predominant view among teachers was called 'scientistic', as scientific knowledge was generally thought to be true, proved and uncontested. That conception of scientific knowledge indeed goes along with scientism. Scientism is a pejorative word used by some philosophers (e.g. Sorell 1991) to denote what they see as science-worship—a reverential attitude and over-estimation of science found in some intellectual circles. The stereotype coming from teachers' responses in the mentioned study, delineates a scientific knowledge which is not tentative because it is certain and objective. Such certain true knowledge is achieved through following the steps of the scientific method and/or relying on neutral, objective observations of natural phenomena.

What counts as scientific knowledge can take diverse forms: descriptions, causal explanations, correlations, models, theories, etc. The so-called coordination among theoretical constructs and evidence has to do with the ways that scientists build and treat their knowledge claims. Scholars' accounts about the boundaries of scientific knowledge frequently refer to distinctive processes of theory building and justification of claims (e.g. O'Hear 1989).

In school science and its long standing emphasis on scientific knowledge, we still find students earnestly copying into their notebooks and repeating knowledge statements as if they were incontrovertible, eternal truths (Claxton 1994). The script of life in the classroom does not often include doubting the authority of a type of knowledge that is taught and learned. While most of the scientific topics featured in school science correspond to well-established knowledge, the stereotype prevents the possibility of understanding why, within certain areas, there is still place for uncertainties. Again, within the logic of stereotypical views of scientific knowledge and scientific method and how both are enacted in school science, a consequence is that teachers can expect students to arrive at scientifically correct ideas after practical work.

In school science teachers introduce students to instances of scientific knowledge which result from methodological processes and social practices rather than from stepwise procedures and/or direct observation of nature. Teaching about concepts or explanatory frameworks require some appreciation that such products of science are not concrete things to 'see out there' but fairly well accepted ideas which also serve as tools to understand and explain natural processes. The limited view of proven and uncontested scientific knowledge is also problematic as it obscures the long and complex ways in which those ideas have been reached by scientists.

3.3 The Conception of the 'Unfamiliar Yet Extraordinary' Scientist

The image of the lonely seeker after truth (Ziman 1968) probably had some connection to scientists working centuries ago. Although time has gone by, idealized views about the people engaged professionally in science seem to be very much unchanged. The stereotypical view of scientists documented by Rampal (1992) suggested that teachers commonly perceive scientists as 'those unfamiliar yet extraordinary beings who though not necessarily trained through the formal educational system, display a keen sense of commitment and patience in their pursuit for truth' and as 'preoccupied personages with a distinct lost look endowed with a scientific temperament that reflects in most aspects of their lives' (p. 432). A very similar stereotype has come from studies exploring students' images of scientists (Petkova and Boyadjieva 1994; Vázquez and Manassero 1998). This suggests that it is quite possible that teachers and student share a very limited view of those whose professional life is developed in science.

Such personal or moral attributes associated to scientists as commitment and patience may play a function as they can be seen as models of rectitude which motivates social recognition. They become kind of heroes, useful among certain school cultures in which individual achievements are praised. The stereotypical view presents them as models of behaviour and not as actors in an intellectual enterprise immersed in a complex social and professional milieu. Again, the oversimplification obscures the richness of possibilities and human diversity that exist in any social group but also among scientists. When scientists are perceived as exceptional persons; the fact that they do their laundry, go to the supermarket, have children or play tennis, as other persons, comes as a surprise. The professional attributes of scientists can also be misrepresented in the stereotype with the image of the solitary scientist working in isolation and obscuring the complexities, social negotiation of knowledge and the division in specialised areas of work.

Oversimplifications can be challenged, for pedagogical reasons, if explicit teaching about scientists is combined with some acknowledgement of the social character of science as a professional sphere. Distinctions could be made among those whose occupations make use of scientific research in some way—computer technologists, physicians and laboratory workers- and those who conduct research that attempts to extend scientific knowledge and understanding (Stevenson and Byerly 1995). Potentially useful would be some sense about different areas of scientific activity, social and institutional contexts where scientists work and about some mechanisms of collaboration and communication they use (Ziman 1995).

The corollary of considering in more detail the former stereotypical views is that to develop a pedagogy of ideas about science, simplistic views can not be sustained. A whole perspective on science comes from views on scientific method, scientific knowledge and scientists: Scientists as the developers of scientific knowledge, scientific knowledge as reliable knowledge, scientific methods as the heuristics to attain scientific knowledge, and finally science as a knowledge generation enterprise. Stereotypes stand for oversimplifications. Much can be gained from the recognition of diversity and complexity over unitary views. It has been recognised that profound changes have taken place in the scholarly understanding of science as a social phenomenon, as a mean of knowledge generation and validation, and as a creative and institutionalised activity (Jenkins 1996). Particularly in the last century philosophers have focused attention on several aspects of science. Russell, Popper, Kuhn, Lakatos, Bachelard and Feyerabend, among others, have contributed to dispelling an idealised conception of science (Nieda and Macedo 1997). Their contributions invite to reconsider, in a more analytical and critical way, aspects like the role of observation as sources of reliable knowledge, the validity of inductive and deductive strategies, the existence of a single scientific method, the status of scientific knowledge as truth or infallible, the effect of dominant ways of thinking in science, the superiority of a theoretical model over others, and science as an individual-driven activity.

4 Discussion and Implications

Research concerning teachers' understanding of the nature of science still has to address critical issues and improve conceptual and methodological approaches. This is important if its findings are to inform the design of strategies to assist prospective and practising teachers to develop their understanding of the world of science and strategies to communicate it effectively to students.

When reviewing studies aimed to elicit or evaluate teachers' understanding, much can be found about its characteristics in terms of adjectives: inconsistent, contradictory, naïve and so on; but clear positions regarding its content features are generally missing. Some ambiguity on the nature of what is to be explored or'evaluated' is revealed in several implicit features of teachers' understanding. In the present analysis, I raised several critics on Nature of Science questionnaires as their limited capacity to explore a wide range of ideas about science, their use of academic normative criteria to assess teachers' responses without sensitivity to the teaching context, their lack of recognition between knowing and doing and their failure to provide feedback for teaching practice, Other critics have been extensively discussed in the work of Cotham and Smith 1981), Lederman et al. (1998) and Lederman (2007). They have severely questioned the construct validity, the biased interpretation and the lack of reliability of especific questionnaires.

I suggested earlier that academic perspectives can not be the yardstick to measure the adequacy of teachers' ideas on the nature of science a priori. That is, that using pre-defined criteria based on the contributions of philosophers and historians of science was counterproductive for the exploration of a wide range of ideas about science that may or may not be defensible from a teaching viewpoint. Assuming beforehand that it is more progressive and desirable that teachers hold a realist-tentative-inventive-subjective perspective on science than an instrumentalist-conclusive-inductive-objective one (e.g. Cotham and Smith 1981) is a prepared ground for disappointment. When informed by academic reflections on the nature of science and taking into account what teachers are expected to teach regarding particular aspects, pedagogical criteria seem to be more fruitful. I tend to agree with Nott and Wellington (1996) when they argue that:

> …Teachers do not necessarily have 'inadequate' views of the nature of science. They have teachers' views of the nature of science which are determined by their academic and professional histories. Teachers do not talk about science as science or science education researchers. Nor do they talk about science as professional philosophers, historians or sociologists (p. 290–291).

Issues about science addressed by scholars surely are different from those addressed by teachers whose sense of what science is, is closely connected to teaching science, an area of human activity which they introduce students to. Such ideas may or may not be appropriate from the perspective of an ideal teaching and learning of ideas about science, but such judgement can not be done without insights on what characterises teachers' thinking in this area. An interesting feature of teachers' practice is that they do not have to reflect consistently upon the nature of science in order to teach science. The story might be different when part of their job is to teach aspects about science explicitly.

Studies exploring teachers' understanding have used a range of research tools: closed and open-ended questionnaires, problematic situations, interviews, think-aloud protocols, stimulated recall, concept maps, ethnographic observation and case studies among others. The present analysis and discussion are limited to the first three research tools. Different methods to study teachers' knowledge and thinking raise important issues about how it is possible to access teachers' knowledge or understanding and the status of the data collected

(Kagan 1990; Haertel 1991; Baxter and Lederman 1999). Teachers' ideas about science seem to be a complex network of ideas that direct and de-contextualised questions, such as 'what are the methods of scientific enquiry?' or close-ended format items are unable to capture. This has to do with the nature of what is to be explored or researched. An individual teacher would tend to display diverse ideas on issues connected to science. This can be called a *conceptual profile* (Mortimer 1995) of ideas about science. Such profile differ from individual to individual and are strongly influenced by the experiences each person has and his or her background. This suggests that individuals might develop a range of qualitatively different ideas about science and use them in different contexts, instead of holding a unique view to be applied systematically in all situations.

Ideas about science are not generally held consciously, well articulated and applied systematically in different contexts (Driver et al. 1996). Teachers might have had limited opportunities to think and reflect about what they know about science. They also might face some difficulties in putting their ideas into words and might be using several ideas in different contexts. Therefore setting the scene in which teachers can articulate their ideas is crucial.

There is a need to achieve more detailed descriptions of teachers' ideas about the nature of science implicit in action than paper and pencil instrument alone are unable to provide. Efforts to develop more authentic probes, combining qualitative research methodologies and move on to questions of classroom practice are possible ways to keep working in this research area.

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