**Proceedings Paper:**

Ryder, J and Martins, AFP (2015) Nature of science in science education: A proposal based on 'themes'. In: Fazio, C and Mineo, RMS, (eds.) Proceedings of the GIREP-MPTL 2014 International Conference. GIREP, 07-12 Jul 2014, Palermo, Italy. Università degli Studi di Palermo . ISBN 978-88-907460-7-9

# Nature of Science in Science Education: a Proposal Based on 'Themes'

**André Ferrer Pinto Martins; Jim Ryder**
*Universidade Federal do Rio Grande do Norte, Brazil; University of Leeds, UK*

**Abstract**
This theoretical analysis addresses some issues related to *knowledge about science* in science education, in general, and in physics education, in particular. We point out the existence of a "consensus view" about Nature of Science (NOS) in science education research literature. Then we argue that: 1) despite its relevance to science teaching, the "consensus view" hides some important divergences that should not be overlooked. In particular, we challenge the idea of the existence of a consensus, showing that there are different routes, terminologies, starting points and conclusions when we analyse literature elaborating this "consensus"; 2) there are some problematic statements in the "consensus view"; and 3) taken (1) and (2) into account, we suggest a more open, pluralistic and heterogeneous approach to deal with the *knowledge about science* in school science curriculum.

**Keywords**
Knowledge about science; nature of science; epistemology; science curriculum

## 1. Introduction
It is not new that the community of science educators acknowledges the importance of learning *about* science within science education. This theme has a long history in the area and remains a challenge to be faced. In addition to the contents present at various teaching levels, a deeper understanding of how science works, how scientific knowledge is produced, validated and communicated, as well as the very nature of this knowledge, in regard to its epistemological particularities, has been seen as something to be sought and of value for science education.
But... *what* to teach? One way to tackle this question is in a negative manner, identifying "what should not be taught". Over the past decades, many works in the area revealed the existence of a large number of misguided and naïve conceptions about science, held both by students and teachers, such as: the empirical-inductive view of science; a rigid (algorithmic, exact, infallible) view of scientific methodology; cumulative and linear views of the History of Science; decontextualized and socially neutral views of the activities of scientists; individualistic and elitist views of science, among others (see, e.g. Driver et al. 1996; Fernandez et al. 2002; Lederman 1992, 2007).
Identifying mistaken and naïve conceptions of scientific work represented significant progress in science education research, and an understanding of what "should not be taught". But one can tackle the issue of "what to teach?" in a positive manner, i.e., seeking to build an understanding of what would be a set of themes, aspects, issues, suitable with the prospect of a teaching about sciences. This path is potentially more complex and it has a long history. Particularly over the past few years it has led to the establishment of what is conventionally called the "consensus view" of the Nature of Science (NOS) – this terminology, incidentally, came to prevail in the specialized literature on this. The so-called "consensus view" (CV) has received diverse types of criticism (e.g. Alters 1997; Rudolph 2000; Clough 2007; Allchin 2011; Irzik and Nola 2011; Van Dijk 2011; Matthews 2012; Dushl and Grandy 2013) while, on the other hand, has been developed and gaining support (e.g. Lederman 1992, 2007; McComas et al. 1998; Osborne et al. 2003; McComas 2008; Abd-El-Khalick 2012a, 2012b). Given this debate it is important to ask: is this the best way to build curricula and think about what to teach?
Following from the above, this article aims to defend three central ideas: (1) Despite its relevance to science teaching, the "consensus view" hides some important divergences that should not be overlooked; (2) There are some problematic statements in the "consensus view"; (3) Taken (1) and (2) into account, we suggest a more open, pluralistic and heterogeneous approach to deal with the *knowledge about science* in school science curriculum.

## 2. The "consensus view": an approach and some criticisms

We begin with point (1). Firstly, it is important to state that, for us, it is clear that a consensus on a philosophical level is unattainable. Science is a much too complex social venture to enable a single characterization. Aware of the lack of consensus on a philosophical level, the consensus view (CV) seeks to present a set of factors about which there would be a broad consensus regarding what is expected to be present in school science curriculum. A pragmatic consensus on certain aspects would be valid for the inclusion of NOS contents in schools. In this sense, the criticism addressed to the CV regarding a lack of consensus among philosophers with respect to a characterization of science (e.g. in Alters 1997) loses some of its strength.

But it is precisely this second level of consensus, valid for school science education, which we will address here. When we look at the specialized literature in this respect we find studies that show the existence of multiple *paths/routes* to build an understanding related to the question "what to teach?" about NOS and also the existence of different *terminologies*, *starting points* and *conclusions*.

Principal texts supporting the establishment of the CV, such as McComas and Olson (1998), McComas et al. (1998) and McComas (2008), e.g., are based on official science education standards documents, whose analysis leads to the creation of NOS tenets. This path may be considered more normative (or nomothetic) and scholarly, and can be illustrated by the very categories used in the classification of the ideas presented in these documents (Philosophy of science, History of science, Psychology of science and Sociology of science), which represent areas of academic knowledge somehow related to the NOS theme.

Others, Driver et al. (1996) and Ryder (2001, 2002) for example, take a different path. In the first case, a description of "what to teach?" is reached starting from an empirical study with students between nine and sixteen years old. The last two works start from an analysis of thirty one case studies related to situations involving the interaction of people with science outside the context of formal education. This results in some suggestions for specific areas of NOS that are needed within school curricula aiming to promote the goals of scientific literacy. This latter path may be considered more empirical and, in a sense, more ideographic (to use the very distinction made by Driver et al. 1996, p. 58).

As a result, there are differences in the conclusions. Although there is significant similarity between aspects of NOS identified in these studies, there are also significant differences. The list of NOS tenets contains short, direct and domain-general statements about science, balancing, in a sense, contents of the four areas (Philosophy of science, History of science, Psychology of science and Sociology of science). In Driver et al. (1996, p. 144-147) we find another classification ("epistemological basis for scientific knowledge claims" and "science as a social enterprise"), whose subcategories are described in more lengthy and exhaustive way. In Ryder (2001, p. 8), the categories with the closest connection to the NOS thematic are: collecting and evaluating date; interpreting data; modelling in science; uncertainty in science, and science communication in the public domain. While issues related to sociology of science appear less represented in the studies of Ryder (2001, 2002), it seems evident that the CV does not consider more deeply the *processes of science*, which arise in such analyses of these latter works cited.

This is an important point. Thus, although McComas et al. (1998, p. 6) state: "There is no one way to do science (therefore, there is no universal step-by-step scientific method)", information on methods does not go beyond this point. Similarly, although we can read in McComas (2008, p. 251) that: "(A) Science produces, demands and relies on empirical evidence" and "(B) Knowledge production in science shares many common factors and shared habits of mind, norms, logical thinking and methods such as careful observation and data recording, truthfulness in reporting, etc.", a more detailed description of what such methods would be, or what is involved in collection and interpretation of data, is missing. Driver et al. (1996, p. 144) suggest the category "evaluation of evidence" that, among other aspects, emphasizes the importance of: "(...) understanding concepts of accuracy, reliability, validity and replicability (...); ways of organizing the collection of data so that logical inferences can be made about the influence of specific variables or features of a system (...)". In Ryder (2001, p. 8) consideration of the processes of science is far more explicit in some of the study synthesis categories: Collecting and evaluating data (Assessing the quality of data and Study design); Interpreting data (Assessing the validity of interpretations in science; correlation and causation; considering alternative explanations; time horizons; Interpretation involves knowledge sources in addition to data; Multiple interpretations in science).

It does not seem appropriate to minimize such differences in routes, points of departure and conclusions, stating for example that the discussion of the processes of science[1] is present implicitly in the CV. The differences are deeper than that and related directly to a consideration of what should be the object of teaching in classrooms and should, in one way or another, be present in curricula. At this point it is worth referring to the work of Osborne et al. (2003), which attempts to reconcile the CV with the results of an empirical study with experts from different fields (science educators, scientists, historians, philosophers and sociologists of science; experts engaged in work to improve the public understanding of science, and science expert teachers). Although there is some correlation between certain NOS *tenets* and *themes* emerging from the study with the Delphi methodology (Osborne et al. 2003, p. 713), it is precisely with reference to the processes and methods of science that correspondence seems unsupported: the ideas of "analysis and interpretation of data" (and the description of what this means) are broader than the CV claim that "science relies on empirical evidence". The same goes for the theme "scientific method and critical testing".

Another aspect of this discussion refers to the terminology present within many works. While the phrase "nature of science" has become commonplace in the specialized literature of science education and can be considered a "catch phrase" (Hipkins et al. 2005), other related studies prefer the term "knowledge about science", "how science works", "epistemology of science" or even "ideas-about-science". This can even be seen in the choice made by the authors in relation to the keywords in each work (recently, an Editorial in Science & Education (Krogh and Nielsen 2013) revealed the existence of a debate about this question of terminology).

The differences pointed out above (in routes, starting points, terminologies and conclusions) suggest some limitation to a consensual perspective, even if restricted to the curricular inclusion of NOS contents. This limitation becomes more evident when we turn to some criticisms of the CV. Clough (2006, 2007), for example, points to the fact that the NOS tenets can be easily distorted by researchers, teachers and students, becoming something to be transmitted – more than investigated – in science classrooms. Thus, he proposes that nature of science aspects should be addressed as *questions* rather than tenets (e.g. "In what sense is scientific knowledge tentative? In what sense is it durable?" instead of the tenet "Scientific knowledge while durable, has a tentative character"). Allchin (2011, 2012) also criticizes the type of declarative knowledge presented in the lists of NOS tenets. For this author, these lists are "inherently incomplete and insufficient for functional scientific literacy" (Allchin 2011, p. 524). They omit many relevant items, for example the significant role of credibility, the social interaction of scientists, the peer review process, cognitive biases, fraud, among others (Allchin 2004, 2011). Irzik and Nola (2011) state that the CV has a number of shortcomings and weaknesses, the main one being to disregard the variations in the detail of nature of sciences across different areas of science. A similar issue had been raised by Rudolph (2000), for whom the particular practices of the various sciences should guide an understanding of the nature of science, rather than a universal conception of what science is. Similarly Matthews (2012) criticizes what he calls the "Lederman Programme", arguing that NOS elements have to be more historically and philosophically refined. He proposes a change in terminology and in research focus: from Nature of Science (NOS) to Features of Science (FOS). Matthews claims that this shift to a more contextual and heterogeneous perspective would avoid some educational and philosophical pitfalls associated with the research in NOS.

## 3. Some problematic statements

Even accepting the limitations and simplifications inherent to the CV as well as the idea that the NOS tenets are general statements that require further detail, we consider that some aspects of the CV are unclear and/or problematic. Take, for example, the idea that "science has developed through 'normal science' and 'revolution' as described by Kuhn (1962)", as appears in McComas (2008, p. 251). The particular view of science provided by Thomas Kuhn, notwithstanding it may have a large number of supporters in the area of science education, is far from unanimous, and this particular epistemology brings together several other controversial notions (e.g.: incommensurability, paradigm). It is entirely legitimate that someone has another view of the historical development of science and does not support to the conception of "revolution". Thus, a commitment to a particular epistemology may be problematic[2].

---

[1] It is important to clarify that when we talk about "processes of science" we are not dealing with didactic strategies or conflating NOS issues and scientific inquiry, as Abd-El-Khalick (2012a) warns. We are referring to an *explicit reflection* on the methods and processes of science.

[2] Although the reference to Kuhn does not appear in all versions and there are certainly other philosophical perspectives underlying the CV, this criticism is addressed to works where that particular 'tenet' is present.

Another important statement says: "Scientific knowledge is tentative, durable and self-correcting (This means that science cannot *prove* anything but scientific conclusions are still valuable and long lasting because of the way in which they are developed but *mistakes will be discovered and corrected as part of the process*)" (McComas 2008, p. 251, second stress added). On the one hand, it is fragile to state that "mistakes" will be discovered and corrected. On the other hand, it is quite plausible that the statement leads to think that a scientist is usually able to discover and correct their mistakes. Here again, a problem arises if we use Kuhn's epistemology. After all, the practice of normal science shows that "errors" are often not fixed (or even perceived) by practitioners. The famous phrase of Max Planck, that a new scientific truth does not thrive because opponents see the reason, but because they eventually die and a new generation grows familiar with the new ideas[3], is emblematic here. It can be said that the statement made by the CV requires a long period of time. Still, the very idea of "errors" seem to be at odds with Kuhn's notion of incommensurability and the idea that scientists who choose different paradigms live in "different worlds", and suggest – implicitly – some linear and cumulative view of the construction of scientific knowledge.
Somewhat more problematic is the statement: "Science has a subjective element. In other words, ideas and observations in science are 'theory-laden'". We agree with the idea that science is "theory-laden". However, it seems to us very different to say that science has a subjective element. These two statements do not say the same thing. One aspect much highlighted within the sociology of science and even by discussions on NOS in the science education area is the way in which science constitutes a socially shared knowledge, constructed collectively in a process of dialogue and, therefore, *intersubjective*. Scientific knowledge is endorsed by the scientific community, in a complex process which includes the peer review process. When we equate "theory-laden" with "subjective element", we get the impression that the *theories* with which we establish our particular look towards the real – shared and socially constructed, *intersubjectively* – are subjective or load of idiosyncratic aspects, and that theories, therefore, are individual, personal.
This view flirts dangerously with a commonsense view that equates "theory" with mere "opinion", "personal view" (sometimes meaning an "abstract" – but still personal – view). It is not uncommon to hear something like: "I have a *theory* it is going to rain tomorrow". Or: "advice is just *theory*; living is always very different". This common usage of the term can have problematic consequences. For example, in the well-known debate between creationism and evolutionary theory, when the latter is seen as a mere "theory" (=opinion). We do not mean here that the CV is not aware of all this or it uses the term "theory" in common sense. The defence of a distinction between laws and theories (one of the NOS tenets) would point in the opposite direction. But the original statement that "science has a subjective element" may give rise to misunderstandings.

Our concern here is of similar nature to that exposed by Clough (2007) in the following passage:

> Nature of science tenets may be easily misinterpreted and abused. Students often see things in black or white. For instance, when addressing the historical tentative character of science years ago while teaching high school science, my students would jump from the one extreme of seeing science as absolutely true knowledge to the other extreme as unreliable knowledge. Extensive effort was required to move them to a more middle ground position. Colleagues have told me of students who have asked why they have to learn science content if it's always changing (Clough 2007).

The conclusion is *not* that the CV should be dismissed or overlooked. What has been said in this section is intended to emphasise that caution should be taken with certain statements (and with the whole set) when we think about curriculum or teacher training programs to deal, in the classroom, with NOS. The deconstruction of misconceptions about science must be accompanied by a careful construction of more current and appropriate views.
Given this complexity of issues and debates, how can the knowledge about NOS derived from research in science education guide the development of curricula? We consider this issue in the following section.

**4. NOS in the curriculum: a proposal based on 'themes'**
The issues (1) and (2) treated in the previous sections lead us to conclude that a more adequate consideration of NOS in science curricula should start from a more open, pluralistic and heterogeneous perspective. The

[3] "A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it". (Planck 1950, p. 33-34).

idea of family resemblance (Irzik and Nola 2011) may be an interesting starting point for thinking about NOS contents. In any case, no list will be exhaustive and it will always have problems. Even if there was a consensus around such a list, enormous difficulties related to assessment and teacher training would remain.
It seems clear to us, at this point, that lists as presented by the CV are useful to have as a reference to consult. An important next step is to construct proposals specially designed to address all levels of education and the various scientific disciplines (here the idea of family resemblance gains strength, since the characteristics of the various sciences, in relation to NOS, are different). As stated by Taber (2008), one should seek an "intellectually honest simplification" when thinking about contents to be taught.
There are several valid approaches. For us, before we get to something like "NOS tenets", it seems reasonable to think of something like "NOS themes". Studies in the literature suggest possible paths. Following closely the book of Driver et al. (1996), we identify two main axes: the *sociological and historical axis* and the *epistemological axis*. The first axis would group themes relating to the role of the individual and the scientific community; intersubjectivity; moral, ethical and political issues; historical and social influences; science as part of culture; communication of knowledge. The second axis, a broader one, would group together themes relating to the origin of knowledge (experience vs. reason; role of observation, experience, logic and theoretical thinking; influence of the theory on experiment), methods, practices, procedures and processes of science (collection, analysis and evaluation of data; inference, correlation and causality; modelling in science; role of imagination and creativity; nature of explanation), and nature/content of the knowledge produced (role of laws and theories; notion of model; similarities and differences between science and other forms of knowledge).
Without intending to create lists or represent that idea exhaustively, we indicate in Table 1 the two axes, with examples of themes that could be explored.

**Table 1** Axes for discussion about NOS content and examples of NOS themes

| ***Sociological and historical route/axis*** | ***Epistemological route/axis*** | | |
|---|---|---|---|
| | Problem of the origin of (scientific) knowledge | Methods, procedures and processes of science | Content / nature of knowledge produced |
| • Role of the individuals/subjects and the scientific community<br>• Intersubjectivity<br>• Historical and social influences<br>• Moral, ethical and political issues<br>• Science as part of a major culture<br>• Aims of science / aims of scientists<br>• Communication of scientific knowledge within scientific community and in a public domain<br>• Historical and contemporary controversies in science<br>• Science and other types of knowledge<br>• Science and technology | • Subject(s) and object(s) of scientific knowledge<br>• Empirical vs. theoretical<br>• Role of observation, experiments, logic, rational arguments and theoretical thinking<br>• Theoretical influences on observations and experiments<br>• {*Differences between scientific areas/disciplines*} | • Collection, interpretation, analysis and evaluation of data<br>• Modelling<br>• Observation and inference<br>• Hypothesis, predictions and tests<br>• Correlation and causality<br>• Nature of explanation in science<br>• Evaluation of theories<br>• Role of analogies, imagination and creativity<br>• Common sense view about scientific method (step-by-step sequence)<br>• Science and other | • Laws and theories<br>• Postulates<br>• Notion of scientific model<br>• Role of Mathematics<br>• Power and limitations of scientific knowledge<br>• Science and other types of knowledge<br>• Science and technology<br>• {*Differences between scientific areas/disciplines*} |

| | | | |
|---|---|---|---|
| • {*Differences between scientific areas/disciplines*} | | types of knowledge<br>• {*Differences between scientific areas/disciplines*} | |

These two major axes are obviously interrelated. The division is to some extent artificial because the aspects properly *epistemic* and distinctive of the "nature" of knowledge produced come from a construction that is collective (intersubjective), *historical* and *social*. The theme of the origin of knowledge (2nd axis), for example, can be put in terms of how it has been seen along the historical and social evolution of science (1st axis). Likewise, a theme like "aims of science" involves both the relationship science ↔ society (1st axis), which historically shaped the goals associated with the construction of this knowledge, as well as the type of relationship subject(s) ↔ object(s) (2nd axis), the basis of this construction. This theme can also relate to the idea of "nature of explanation in science" (2nd axis), since the way explanations and justifications of scientific knowledge are given relates to the goals and objectives associated with this knowledge.

A theme that can be approached from different perspectives is "science and other types of knowledge". Considered from a historical and sociological (1st axis) point of view, we might explore historical and social differences between distinct cultures, as well as the gradual consolidation of science as a body of systematized knowledge, differing over the centuries from other forms of knowledge. From an epistemological point of view (2nd axis), the proper *methods and processes of science* are crucial to understand the differences between scientific and other types of knowledge. Moreover, it is precisely with regard to the *nature/content of knowledge produced* that distinctive features of science might be explored, such as its conjectural character, the notion of truth (not absolute), the idea of ruptures and continuities, the nature of change in science, the ideas of prediction, internal consistency and simplicity as well as characteristics of scientific language.

We conclude these brief comments about the Table 1 by pointing out that the *differences between scientific areas/disciplines* is something to be addressed under the different axes and themes. Historical (1st axis) differences, as well as epistemological (2nd axis) differences, such as the various methodologies used in different areas (in vitro, in vivo, double blind tests etc.), would be the object of attention. In this aspect, contextual and specific aspects of the various areas could be better explored.

A further analysis might involve taking these axes and themes and describing in more detail what should be taught. This would lead us to something similar to the NOS tenets proposed by CV (although works of this kind do not address exactly these same axes and themes). In a sense, the work of Abd-El-Khalic (2012a, 2012b) follows this direction by suggesting a spiral curricular structure in which a certain aspect of NOS would be addressed at different levels of depth along the formal education at many school levels. This path is valid and may undoubtedly be a guide for curriculum development.

We believe, however, that the very arguments exposed in this work justify another approach. It is important to remember that structuring and *designing* curricula is a broader and more complex process that involves – or should involve – a range of social actors (educators, scientists, politicians, members of the school community, teachers, parents and communities in general, students) and not just science educators. Thus, these axes and themes themselves could be guides for curricular choices (with subsequent definition about NOS contents) which would be built from more particular/specific contexts provided, e.g.: by specific scientific areas and subject matter contents; by school level; by local, regional and national issues of interest, among others. In short: working from major axes and themes, the details would come up in a more contextualized manner. This contemplates, to some extent, the flexibility necessary to incorporate the plurality of views on aspects of NOS, especially with respect to the various scientific disciplines. Additionally, it prevents premature formulation of "general principles" on NOS that does not need to be present at that time. Thus, the use of themes would avoid many problems associated with the CV and the NOS tenets, providing a more open and plural approach in the treatment of NOS issues in school science curriculum[4].

Certainly this detailing process will be informed by the knowledge built in science education area about these axes and general themes. We see here the fields of History, Philosophy and Sociology of Science

[4] Certainly other perspectives are possible, such as, e.g., the notion of 'structuring theoretical fields of the philosophy of science' (Adúriz-Bravo 2004; Adúriz-Bravo and Izquierdo-Aymerich 2009; Adúriz-Bravo et al. 2002) which, although it has been developed in the context of pre- and in-service science teachers, could be another starting point for thinking about curricula designs. In a similar context (trainee teachers), Taber (2008, see Appendix) presents a document used in Cambridge that provides a basis for thinking about planning curriculum models to teach aspects of NOS.

*feeding* the discussion around these axes and themes. Without a reasonable minimum knowledge of these fields, the detailing of these themes would mean very little. Worse than that, it may result in a list of dogmatic assertions that mixes diverse views and does not become operational, being rejected in the future – and in practice – by science teachers in schools.

## 5. Conclusion

Notwithstanding its diverse meanings, the scientific literacy of the general population continues to be a goal of many those concerned with science education. Science should not be presented to students at schools in a dogmatic way and/or limited to the knowledge of science *content* – seen, wrongly, as a set of facts and claims about phenomena. In this sense, a scientific literacy should also embrace *knowledge about science*. Research in science education has advanced significantly in this direction, and we are today in a better position to inform educators in general, and curricula developers in particular, in relation to such *meta*scientific content. As is characteristic of the humanities, the complexity and richness of ideas remains a virtue to be considered. In this sense, the search for a consensus view may be an arduous task.

Our attempt in this work was to signal the difficulty of this consensus and some other issues that emerge from the so-called consensus view and deserve attention. We consider appropriate that the perspective of inclusion of NOS themes in science curricula has a wider and pluralistic starting point that, to some extent, incorporates what has been discussed in the literature. The approach of many groups, such as science educators, historians, philosophers, sociologists, scientists, educators in general, teachers and other members of school community, tends to be fundamental to the development of curricula that make sense of, and respond to, social demands.

## Acknowledgements

The main author wish to thank Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES/Brazil) for financial support of the research project related to this publication (process number 4044-13-4).

## References

Abd-El-Khalick, F. (2012a). Examining the sources for our understandings about science: enduring conflations and critical issues in research on nature of science in science education, *International Journal of Science Education* **34**, 353–374.

Abd-El-Khalick, F. (2012b). Nature of science in science education: Toward a coherent framework for synergistic research and development. In Fraser B.J., Tobin K. and McRobbie C. (Eds.), *Second international handbook of science education* (pp. 1041-1060). The Netherlands: Springer.

Adúriz-Bravo, A. (2004). Methodology and politics: a proposal to teach the structuring ideas of the philosophy of science through the pendulum, *Science & Education* **13**, 717–731.

Adúriz-Bravo, A. and Izquierdo-Aymerich, M. (2009). A research-informed instructional unit to teach the Nature of Science to pre-service science teachers, *Science & Education* **18**, 1177–1192.

Adúriz-Bravo, A., Izquierdo-Aymerich, M. and Estany, A. (2002). Una propuesta para estructurar la ensenãnza de la filosofía de la ciencia para el profesorado de ciencias en formación, *Ensenãnza de las Ciencias* **20**, 465–476.

Alters, B. J. (1997). Whose nature of science? *Journal of Research in Science Teaching* **34**, 39-55.

Clough, M. P. (2007). Teaching the nature of science to secondary and post-secondary students: questions rather than tenets, *The Pantaneto Forum* **25**.

http://www.pantaneto.co.uk/issue25/front25.htm. Accessed 25 May 2014.

Driver, R. H., Leach, J., Millar, R. and Scott, P. (1996). *Young people's images of science*, Open University Press, Buckingham, UK.

Dushl, R. A. and Grandy, R. (2013). Two views about explicitly teaching Nature of Science, *Science & Education* **22**, 2109-2139.

Fernández, I., Gil, D., Carrascosa, J., Cachapuz, A. and Praia, J. (2002). Visiones deformadas de la ciencia transmitidas por la enseñanza, *Enseñanza de las Ciencias* **20**, 477-488.

Hipkins, R., Barker, M. and Bolstad, R. (2005). Teaching the 'nature of science': modest adaptations or radical reconceptions? *International Journal of Science Education* **27**, 243–254.

Irzik, G. and Nola, R. (2011) A Family Resemblance Approach to the Nature of Science for Science Education, *Science & Education* **20**, 591-607.

Izquierdo, M. and Adúriz-Bravo, A. (2003). Epistemological foundations of school science. *Science & Education* **12**, 27-43.

Khishfe, R. (2013). Transfer of Nature of Science understandings into similar contexts: promises and possibilities of an explicit reflective approach, *International Journal of Science Education* **35**, 2928-2953.

Krogh, L. B. and Nielsen, K. (2013). Introduction: How Science Works - and How to Teach It, *Science & Education* **22**, 2055–2065.

Lederman, N. G. (1992). Student's and teacher's conceptions of the nature of science: a review of the research, *Journal of Research in Science Teaching* **29**, 331-359.

Lederman, N. G. (2007). Nature of science: past, present and future. In Abell, S.K. and Lederman N.G. (Eds.), *Handbook of research on science education* (pp. 831-879). Mahwah, NJ: Lawrence Erlbaum Associates.

Matthews, M. R. (2012). Changing the focus: from nature of science to features of science. In Khine M. S. (Ed.), *Advances in nature of science research* (pp. 3-26). Dordrecht: Springer.

McComas, W. F. (2008). Seeking historical examples to illustrate key aspects of the nature of science, *Science & Education* **17**, 249-263.

McComas, W. F. and Olson, J. K. (1998). The Nature of Science in international science educational standards documents. In McComas W. F. (Ed.), *The Nature of Science in Science Education: rationales and strategies* (pp. 41-52). The Netherlands: Kluwer.

McComas, W. F., Almazroa, H. and Clough, M. (1998). The Nature of Science in Science Education: an introduction, *Science & Education* **7**, 511-532.

McComas, W. F., Clough, M. and Almazroa, H. (1998). The role and character of the Nature of Science in Science Education. In McComas W. F. (Ed.), *The Nature of Science in Science Education: rationales and strategies* (pp. 3-39). The Netherlands: Kluwer.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R. and Duschl, R. (2003). What ''Ideas-about-Science'' should be taught in school science? A Delphi study of the expert community, *Journal of Research in Science Teaching* **40**, 692-720.

Planck, M. K. E. L. (1950). *Scientific autobiography and other papers*, Williams & Norgate, London, UK.

Rudolph, J. L. (2000). Reconsidering the 'nature of science' as a curriculum component, *Journal of Curriculum Studies* **32**, 403-419.

Ryder, J. (2001). Identifying science understanding for functional scientific literacy, *Studies in Science Education* **36**, 1-44.

Ryder, J. (2002). School science education for citizenship: strategies for teaching about the epistemology of science, *Journal of Curriculum Studies* **34**, 637-658.

Taber, K. S. (2008). Towards a curricular model of the Nature of Science, *Science & Education* **17**, 179-218.

Van Dijk, E. M. (2011). Portraying real science in science communication, *Science Education* **95**, 1086-1100.

**Affiliation and address information**

André Ferrer Pinto Martins
CE - Centro de Educação, Universidade Federal do Rio Grande do Norte
Campus Universitário, BR 101, Lagoa Nova
59072-970 Natal, RN, Brazil
email: andre.ferrer@pq.cnpq.br ; aferrer34@yahoo.com.br

Jim Ryder
CSSME - Centre for Studies in Science and Mathematics Education University of Leeds

School of Education
LS2 9JT Leeds, United Kingdom
email: J.Ryder@education.leeds.ac.uk