Teaching about nature of science in secondary education: a view from multicultural classrooms

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Teaching about nature of science (NOS) within a science curriculum that is primarily concerned with developing scientific content continues to provide a challenge for teachers. This study of science lessons focuses on whether NOS is being incorporated implicitly or explicitly, and whether epistemic aspects (e.g. models, theories) and social aspects (e.g. controversies, ethics) are addressed in a range of topics. The study raises questions around how teaching NOS can remain on the agenda in a content-heavy curriculum and how it can be important to the reality of multicultural classrooms.

In recent decades, 'teaching about science' has been advocated by many science educators (e.g. Driver *et al*, 1996; Erduran & Dagher, 2014; Hodson, 2014) as an important part of school science that can open up the scientific world to a larger and more diverse number of students. This idea is associated with the comprehension of science as an enterprise, as a world that has its own 'nature', is organised, and functions under some patterns. Historically, studies of the philosophy of science are closely associated with this nature, often called 'nature of science' (NOS), and contributions from fields such as sociology and history have also cast light on this topic.

But what is this 'nature of science'? Diverse ways of understanding science have produced several debates among science educators in relation to what NOS should be. For the investigation reported here, I work with a model that views NOS as encompassing two main dimensions:

- **epistemic** – the nature of scientific knowledge, that is, how science develops and tests knowledge, e.g. models, theories, experimentation; and
- **social-institutional** – how science is a socio-cultural endeavour, e.g. controversies, ethics, certification/negotiation of knowledge.

This model is mainly inspired by the theoretical work of Erduran and Dagher (2014) on philosophy of science and NOS, and is also closely related to findings from empirical research on students' views about NOS carried out by Driver *et al* (1996) and Billingsley *et al* (2016).

This way of understanding NOS, with its epistemic and social-institutional dimensions, can be very relevant to science teachers when they plan the introduction of discussions about science and its nature into their lessons. This is mainly because this model highlights that 'working scientifically' and 'how science works' topics encompass not only aspects related to empirically based processes of knowledge production (epistemic dimensions), but also to how science is a social and cultural endeavour itself and, thus, it involves activities and relationships beyond collecting and analysing empirical data.

More importantly, this model also acknowledges that both dimensions usually overlap and inform each other during scientific research (Erduran & Dagher, 2014). This holistic perspective of NOS seems to offer the science teacher an interesting pathway to connect, during lessons, scientific content to NOS, since both of them are seen as part of a broader process of knowledge development, and also to connect science to other fields, such as economics, politics, history and religion (Billingsley *et al*, 2016).

However, beyond this idea of how we understand NOS, what is the best approach to its inclusion in regular school science? Obviously, there is not just one way of incorporating NOS into school science, but there are some investigations within the field of science education that, like this research, try to generate theoretical and empirical guidance about this topic.

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One of the main debates is related to whether NOS should be taught implicitly or explicitly. The first approach involves working with aspects of NOS inserted in a regular lesson without being specifically addressed by the teacher: that is, NOS learning is understood as a by-product of a more general activity and not as a planned outcome. The explicit perspective, on the other hand, aims to address NOS clearly in order to assist students in reflection about these aspects with the help of the teacher (Fouad, Masters & Akerson, 2015).

These two approaches have been extensively investigated and a general consensus seems to have been achieved on the more beneficial impacts of the explicit perspective. Twenty years ago, Driver *et al* (1996), for instance, stated that science lessons can convey implicit messages about NOS to students all the time, even when it is not the main purpose of the lesson; therefore, they questioned the impact of such an (implicit) approach on distorting students' views about science, since these ideas are not explicitly discussed. More recently, Deng *et al* (2011), while reviewing empirical works involving NOS teaching, concluded that explicit approaches appear to offer better results in school interventions designed to change students' views about NOS than implicit ones.

Teaching about science from a more explicit and contextualised perspective seems to open up an interesting possibility in relation to another relevant debate surrounding science education: its teaching in multicultural contexts. In a global scenario of cultural exchanges, where a wide range of students from different backgrounds are learning about science, many of them also have to deal with their world-views in situations where modern science and their cultural traditions can conflict (Krugly-Smolska, 2013; Sarukkai, 2014).

However, I agree here with some authors (such as Nola & Irzik, 2005 and Matthews, 2014) that the relationship between modern science and culture does not need to be adverse, at least in school science settings. The goals of science teaching, in this case, should not be to indoctrinate students, but to equip them with skills to make critical assessments for themselves regarding modern science and historical and traditional knowledge, as well as to understand this modern science as a result of historical processes of intercultural exchanges and contributions from different people, communities and ways of seeing the world – that is, an *'intercultural perspective of science'* (Matthews, 2014; Sarukkai, 2014). Thus, by bringing real (contemporary or historical) contexts of scientific development to the classroom and by actively discussing them with their students in terms of NOS, I believe that science teachers can not only improve students' understanding about, but also their engagement with, modern science.

In this context of different ways of incorporating NOS into school science and of how science is taught in terms of its own intercultural origins, the study reported here investigated science teachers' practices in two multicultural schools in London, UK, being informed by the following research questions:

- How do science teachers incorporate (or not) discussions about NOS into their lessons?
- Are they taking the intercultural aspects of modern science into account when doing so?

Carrying out the classroom-based investigation

This research was a qualitative classroom-based study that investigated science lessons in two multicultural state secondary schools (schools A and B). The methodology involved observing these lessons to describe teachers' practices in relation to teaching about NOS in a context of cultural diversity.

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School A is a school from northwest London, which has a long-term association with academic research; school B is a comprehensive Catholic single-sex school for girls in north London. Both schools are evaluated as 'outstanding' by Ofsted and are attended by a highly multicultural intake (at least 50% of students with English as a second language). Schools A and B have, respectively, around 860 and 900 students in their curriculum cycles known as Key Stages 3 and 4 (KS3 and KS4, ages 11–16). In school A, the KS3 cycle comprises Years 7 (ages 11–12) and 8 (ages 12–13), and the KS4 cycle comprises Years 9 (ages 13–14), 10 (ages 14–15) and 11 (ages 15–16). Meanwhile, in school B, Years 7, 8 and 9 are part of KS3, and Years 10 and 11 are part of KS4. It is important to remark that school A adopts a different approach to the organisation of their curriculum cycles from what is suggested by the English National Curriculum: instead of working with Year 9 as part of the KS3 cycle (as traditionally done by most English schools, such as school B),

Table 1: Summary of lessons observed during the exploratory phase

School	Year	Ability group	Teacher	Subject	Topics
A	8 (KS3)	mixed	F	science	drugs and alcohol inheritance (genetics) space magnetism
	9 (KS4)	set 1	F	biology	microscope animal and plant cells stem cells
		set 2	B	chemistry	energy changes
			F	biology	microscope animal and plant cells stem cells
		set 3	B	chemistry	electrolysis energy changes
	10 (KS4)	set 1	P	chemistry	Earth's atmosphere
		set 2	P	chemistry	Earth's resources
B	8 (KS3)	set 2	A	science	magnetism inheritance and natural selection
	9 (KS3)	set 3	K	science	universe radioactivity turning points in chemistry
	10 (KS4)	set 1	K	biology	stem cells

they consider this year group as part of KS4, teaching topics from the KS4 curriculum one year earlier than usual.

A total of 50 science lessons were observed in Years 8, 9 and 10 (ages 12–15) at both schools, involving five teachers, nine classrooms (described by the schools as low, high and mixed abilities), and different topics in biology, chemistry and physics. Table 1 on page 13 summarises relevant information about the participant classes in both schools, including classrooms, subjects and topics observed.

The choice of topics to be observed (3–4 lessons per topic) was made with the help of the participant teachers after informal conversations about NOS in school science, and was also based on some teaching experiences found in the literature about NOS. Thus, these teachers were actively involved in the selection of topics they felt were closely connected to the aims of this study, such as universe/space, stem cells and radioactivity.

Data were collected using field notes and audio-recordings, paying special attention to which example(s) teachers were using and whether and how they were using them to teach about NOS. Data were analysed qualitatively in order to build an account of science lessons and an understanding of teachers' practices. I was not concerned with categorising these teachers in some pre-conceived groups, but instead with observing and describing their experiences when engaging with this specific aspect of school science.

Findings: talking about science and its nature

While talking about NOS, the teachers observed during this investigation usually opted for an emphasis on one of the two main dimensions of NOS discussed in my introduction: epistemic or social-institutional. This is not to say, however, that those teachers were necessarily aware of this model that views NOS as encompassing both epistemic and social-institutional features. What seems to happen, in fact, is a natural division when teaching about NOS, where teachers usually focus on epistemic topics or on social-institutional ones, with rare occasions when both of these dimensions are part of the same lesson.

The epistemic dimension of NOS encompassed aspects related to the purposes of science and the nature of its knowledge and practices, such as models, variables, evidence, fair testing and double-blind investigation. This was the case, for instance, in Teacher B's lesson on activation energy (Year 9), in which she employed molecular models to explain the process of breaking and forming bonds between atoms and the energy change involved. While working with concrete and coloured models, the teacher highlighted the difference between them and the actual molecules they were representing, as seen in Box 1.

Even though briefly emphasising the use of these kits as models and not as a real representation of the molecules, the teacher did not opt for developing an explicit discussion on the role of models and other forms of representation in science. In this example, the introduction of NOS aspects was done implicitly, that is, as a by-product of the activity, without being specifically addressed by the teacher. During the lessons, this implicit approach was often seen when NOS aspects were related to its epistemic dimension. In other words, when teaching NOS involved epistemic features, such as models, evidence and theories, the participant teachers usually adopted an implicit stance.

This situation was also seen in Teacher P's activity on actions and consequences (Year 10), which involved a game where students had to analyse different actions (e.g. going vegan, banning cars) and predict their consequences in relation to the environment, people and money. Here, students worked in groups to analyse information about each

BOX 1. Extract from Teacher B's Year 9 lesson on activation energy

Teacher: *Everyone used these model kits before? I think you have . . .*

Students: *Yes!*

Teacher: *Right! So molecular model kits . . . the way they work is that we've got different colour beads that represent different atoms. . . . These black beads, when you get to use the model kits, they represent carbon atoms. The reason why these can only represent carbon atoms is because they've got four holes built into it, and that's because carbon atoms can form four bonds and they only form four bonds. OK? The hydrogen are these . . . so guess how many bonds hydrogen can form . . . Are you seeing just one hole? Right, it can form one bond. And then the only other atom that you'll need for this bit is the red ones, which represent?*

Student: *Oxygen.*

Teacher: *Brilliant! An oxygen has two holes, therefore it can form two bonds.[Gap while the students work with the models]*

Student: *What are the bonds made of? [looks at a model he built for methane]*

Teacher: *What are bonds made of? You know in these model kits we are using little sticks? Actually, it's not really a stick, it's like an overlap of the two atoms. So if you imagine this is a hydrogen [shows one model bead], and these are hydrogen's electrons [shows one stick], and the electron is like doing this [connects the stick to the bead], another atom of hydrogen will overlap with it and then the electrons will then go around this one as well [shows the second ball]. So, that's it, they've completed their shells. So, it's not really a stick like that, it's more of an overlap of two circles, OK?*

action and then decided the predictable consequences of these actions, also employing other sources of information, such as topics learned in other lessons, subjects and out-of-school knowledge. When Teacher P asked the students to evaluate evidence in order to predict the consequences of a chosen action, no discussion was carried out about the actual meaning of 'evidence' and 'prediction' in science; that is: what scientific evidence is, which types and sources of evidence are employed, how they are obtained, what the relationship between evidence and prediction is, the process of analysing evidence leading to a prediction, what a prediction is, and so on. By asking students to 'use evidence' from the handouts and also based on their previous knowledge on the topic, and to 'make predictions', without discussing the meaning of these concepts, the teacher created a scenario where they worked under an 'anything goes' perspective, leading to answers where pieces of evidence were not in fact used, but invented by students to make a prediction possible.

In contrast, some explicit approaches towards NOS were sometimes seen in discussions about its epistemic dimension. Unlike Teacher B's approach to models in science, Teacher K's lesson on the theories of the Earth (Year 9) involved an explicit discussion about this epistemic dimension of NOS. This included an initial prompt where students had to write down their own definition for 'model' (*'What's a scientific model?'*) and share their answers with the group. Starting from their answers (*'a 3D structure', 'a plan', 'a clone of something', 'a type of physical diagram'),* the teacher then talked about a model being physical or mathematical and about how it is used to understand what we investigate and sometimes cannot see, and also to make predictions about what will happen.

Another situation where epistemic aspects of NOS were explicitly addressed was found in discussions about inquiry tasks or examples. In these cases, features such as fair testing, variables, measuring and instrumentation promoted an active and explicit talk between teacher and students, where

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reflections about their meanings and importance in science were carried out. Teacher F's lesson (Year 8) on drug trials, which started with a short video about the main steps of clinical trials, was intrinsically and explicitly connected to inquiry aspects of NOS. The teacher promoted these active discussions about important stages of scientific research, with special emphasis on control versus experimental groups, double-blind testing, fair tests/trials, and so on.

Likewise, while presenting the history of the thalidomide case to this same group of students (Year 8), Teacher F discussed aspects of testing in science and the possibility of errors in experimental designs. It is also worth noting how, during this lesson, the explicit work on epistemic aspects of NOS also opened up the debate to its social-institutional dimension, connecting this process of trialling with discussions about morals and ethics in research, including animal testing (a student: *'What's the difference between a human and an animal life?'),* volunteer selection (a student: *'Why were all the volunteers white?')* and impacts on people's lives (students asked about mothers suing the company). This approach built up a clear picture of science as a process of knowledge production, involving not only several and long-term stages of intensive research in different levels such as laboratory, animal and human testing, but also ethical and moral dimensions from its starting point.

When introducing this social-institutional dimension of NOS into their lessons, teachers talked mainly about aspects related to the connection between science and society, such as ethical and cultural values, politics and economics of science – its 'external level', and to social and institutional work within the scientific world, such as scientific conferences and processes of certification – its 'internal level'.

Discussions about this internal level were part, for instance, of Teacher F's 'marketplace' activity during a lesson on drugs and alcohol (Year 8), in which students had to select, present and exchange information on different drugs, acting as 'researchers'. This activity encompassed not only the study of one specific drug, but also the construction of a poster to be presented during a poster session, where other students had to circulate and ask questions about each other's posters.

Nevertheless, discussions about the social-institutional dimension of NOS usually placed more emphasis on the relationship between science and society – its external level – than on the discussions about social and institutional aspects within the scientific culture – its internal level. This seems to be linked to an easiness, from the point of view of school science, of working on the borders of the scientific world, that is, between science and society, not fully entering the scientific world in order to understand its specific and complex internal ways of operating.

Teacher K's lesson on the theories of the Earth (Year 9), for instance, even though explicitly addressing the concept of 'scientific models', avoided having an in-depth discussion about why scientists can develop different theories about a phenomenon (processes of certification, controversies, different theoretical standpoints, instrumentation, etc.) by only stating that *'it is difficult to prove a theory'.*

Similarly, this situation was also seen during Teacher P's lesson on global warming with a Year 10 group, when she opted not to discuss the presence of contradictory evidence and explanation in the current debate surrounding this topic (internal level), talking only about its future implications to the planet (external level). That is, even though she mentioned the existence of this contradictory scenario, no further attempt was made to clarify it, which would include discussions not only about epistemic NOS aspects such as measurement, instrumentation, evidence and

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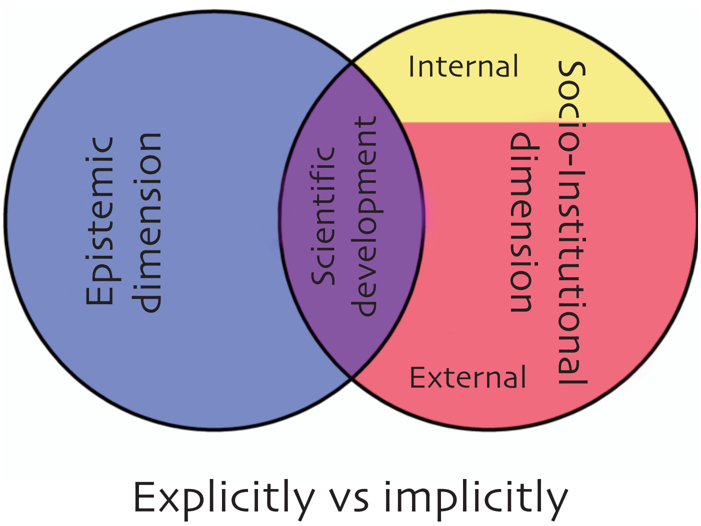
explanations, but also about its internal features as a social institution, such as certification, negotiation and conflicting explanations.

Figure 1 summarises the main approaches towards NOS teaching observed during these lessons, not only in terms of which aspects of NOS were being addressed – epistemic or social-institutional dimensions, but also how these aspects were introduced into the lesson – implicitly or explicitly.

It is worth noting that there were also cases where no explicit discussion about nature of science was actually carried out by the teacher, more emphasis being placed on teaching scientific content than on the processes of production of scientific knowledge. This absence of reflection about NOS during science lessons is itself understood here as one specific view about NOS: an authoritarian one, which very often approaches scientific knowledge as 'ready-made', that is, as 'given' by objective and neutral sources of information such as scientists and textbooks. In other words, it is important to acknowledge that when teachers do not incorporate discussions about science and its nature into their lessons, a specific view of science as authoritarian and unquestionable, content-driven and disconnected to general society, or as only dedicated to the production of goods and appliances, is being portrayed to students.

Figure 1: Dimensions of NOS and its insertion in school science



Nevertheless, during the observed lessons, discussions about science and its nature with students were seen more as a continuum (more or less emphasis on NOS) than a clear-cut division between 'without NOS' and 'with NOS'. Thus, there can be different approaches towards NOS teaching, ranging from lessons with no explicit talk about it to lessons with examples involving some specific aspects of NOS, and finally to lessons encompassing more discussions connected to NOS than to specific scientific content.

Final thoughts

During this investigation, special attention was dedicated to how teachers teach about NOS in their contexts of cultural diversity. As an overall finding, there was an emphasis on scientific content, with less attention to explicitly teaching about NOS. This situation is common in current school practices, where the main goal of a secondary science lesson is learning a scientific concept rather than developing scientific skills or thinking about nature of science. In this context, it seems reasonable to expect that the majority of science teachers dedicated a large proportion of their lessons to the teaching of a specific scientific concept rather than NOS.

One interesting finding from this study is that teaching about science was more common in KS3 than in KS4 groups. This highlights how the curriculum and assessment demands, the driving force behind contemporary education, can also impact on which aspects of scientific knowledge are addressed in the lesson. Thus, it seems that while KS3 topics and possibly the lack of an end-of-stage assessment offer more freedom to the teacher to discuss NOS, GCSE exams at the end of KS4 seem to be an obstacle to more in-depth and diverse talks about how science works. In this last case,

discussions about NOS are usually restricted to GCSE questions on topics such as global warming (Teacher P's lesson with a Year 10 group) and stem cells (Teacher K's lesson with a Year 10 group). Thus, teaching about NOS, within a science curriculum that is primarily concerned with developing knowledge and understanding of scientific content, continues to provide a challenge for teachers around the most appropriate strategies to use.

It is worth noting, however, that even though these discussions about NOS were not very often part of KS4 lessons, an implicit view of science is being communicated by the teacher when she opts not to address these ideas with her students. As previously argued, the choice of teaching science solely as an end product, without reflections about the process of knowledge production, can easily lead to students having dogmatic and distorted views about science (e.g. objective, value-free, neutral and apolitical). Here, the importance of teaching about NOS must once again be stressed, in order to avoid the perpetuation of an image of science as disconnected from general society, antisocial and individual, which can influence people's attitudes towards scientific development and careers (Christidou, 2011).

This content-driven perspective of school science can also account for the lack of diversity in the examples chosen by the teachers to teach about NOS. That is, not only can it affect how the topics are being addressed (discussions about NOS), but also which examples are being employed. Even though it can be argued that modern science is highly dependent on contributions from different communities and people from around the world (Matthews, 2014; Sarukkai, 2014), very few examples discussed by the teachers in this study mirrored this diversity, placing a heavy emphasis on Western applied knowledge and dedicating little attention to knowledge production by other communities and countries.

This scenario raises questions about the lack of diversity, not only cultural, but also in terms of gender, while teaching about science and scientific development and its impacts on students' views about scientific communities and the professional and cultural identities of science. Even though I acknowledge here that this is not simply a teacher's choice, since teaching materials that introduce these intercultural and more culturally diverse views about modern science are scarce (as rightly pointed out by Krugly-Smolska, 2013 and Sarukkai, 2014), it is important to remember that this choice of examples exclusively from Western science scenarios and scientists also conveys an implicit and very narrow view of science, especially about who can participate in the scientific world and who can actually contribute to it (Christidou, 2011; Sarukkai, 2014).

In summary, based on the results from this investigation, I argue that the option for an emphasis, during science lessons, on only scientific content, to the detriment of discussions about who can participate in science, how scientists work, and how and why scientific knowledge is produced, communicated, assessed and debated, can inevitably lead to a very narrow view of the scientific world. In contrast, as illustrated by the approaches of Teachers K and F in their lessons on, respectively, theories of the Earth and drug trials, an explicit and reflexive discussion about science and its nature (including social and intercultural aspects) can result in a more interesting and diverse lesson, involving more debates, and bringing in students' own ideas and interests about the topic.

These examples of science lessons where NOS was explicitly introduced by the teachers alongside the scientific content are a clear indication that, even if they still face several challenges in terms of curriculum and assessment, talking about science and its nature can in fact be done in everyday practice. When NOS is introduced as a way of

discussing the importance of models, experiments, theories, scientific collaborations, ethics, communication and so on, to the development of specific school science content, this opening up of the scientific world can help us tackle students' negative attitudes towards science, scientists and scientific careers.

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