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FORUM

In defence of non-epistemic aspects of nature of science: insights from an intercultural approach to history of science

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Abstract
The focus of this article is to expand María del Mar Aragón, José Antonio Acevedo-Díaz and Antonio García-Carmona's paper "Prospective Biology teachers' understanding of the nature of science through an analysis of the historical case of Semmelweis and childbed fever" by focusing on the discussion about teaching non-epistemic aspects of NOS. This article will draw on my own research at secondary schools in London, U.K. to illustrate different possibilities to broaden this inclusion of non-epistemic aspects into school science through the use of an intercultural perspective to History of Science, that is, to how historical cases are employed to teach about NOS.

Keywords Nature of science · History of science · Intercultural science · Science teaching

In their article "Prospective biology teachers' understanding of the nature of science through an analysis of the historical case of Semmelweis and childbed fever", María del Mar Aragón, José Antonio Acevedo-Díaz and Antonio García-Carmona adopt a model of nature of science (NOS) that consists of epistemic and non-epistemic aspects to describe how scientists and scientific communities operate. They conceptualise teaching about NOS as encompassing discussions about "cognitive or rational aspects related to both scientific knowledge and the science's processes and methods" (p. 1)—science's epistemic dimension—, and also about "contextual, social and psychological aspects related to science and scientists" (p. 2)—science's non-epistemic dimension.

In this article, I will argue for an expansion of their specific defence of the teaching of non-epistemic aspects of NOS as part not only of teacher training programmes (as in the case of the article in discussion), but also of regular school science. This defence will

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This review essay addresses issues raised in María del Mar Aragón, José Antonio Acevedo-Díaz and Antonio García-Carmona's paper entitled: Prospective Biology teachers' understanding of the nature of science through an analysis of the historical case of Semmelweis and childbed fever. https://doi.org/10.1007/s11422-018-9868-y.

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engage with important discussions in the field of Science Education, highlighting that the view of NOS introduced into science lessons is intrinsically connected with specific views of science and school science. This article will draw on my own research at secondary schools in London, U.K. to illustrate different possibilities to broaden this inclusion of non-epistemic aspects into school science through the use of an intercultural perspective to History of Science (HOS), that is, to how historical cases are employed to teach about NOS.

The teaching of non-epistemic aspects of NOS: beyond traditional approaches

The rationale behind the advocacy of NOS in Science Education is part of a larger reflection on science and scientific communities that was jump-started by contemporary studies about History, Philosophy and Sociology of Science in the 1950s and 1960s, and that led to advocacy for the change in how the production of scientific knowledge is portrayed (Hodson 2014). The challenge was to stop analysing science as only a useful and necessary product to life in modern societies, and start reflecting about it as part of a process involving negotiation, norms, ethics, and different levels of complexity (political, economic, ideological)—that is, the non-epistemic aspects of NOS (Erduran and Dagher 2014).

Peter McLaren discussed some of these ideas in an interview with Angela Calabrese Barton (2001) about how the relationship between capitalism, power and production of scientific knowledge has deeply influenced the way most countries in the Western world view Science Education. According to McLaren, "the marriages between capitalism and education and capitalism and science have created a foundation for science education that emphasises corporate values at the expense of social justice and human dignity" (p. 847). In other words, solely utilitarian, neoliberal and triumphalist views about science end up being advanced by most curricula and practices in Science Education without critical reflection or acknowledgement of its limitations, implications, and political, economic and ethical commitments: "what I am suggesting is that we find ways to critically examine the relationship between corporate power and the knowledge we label for our students as 'objective' and 'true'" (Barton 2001, p. 850).

He further elaborates by explaining how dominant views of science as objective, neutral and progressive[1] that are entrenched within capitalist and progress-driven societies often "dehistoricize knowledge", restricting the possibilities of a critical analysis of scientific development as neither neutral and objective nor disconnected from political, economic, ideological, cultural and ethical aspects (Barton 2001). The challenge seems to acknowledge that, as also discussed by Douglas Allchin (2004), the non-epistemic aspects of NOS are indeed a critical part of the process of production of scientific knowledge and, for this reason, they are important to an understanding of scientific work as inherently complex, cultural and value-based.

The process of "dehistoricization" of scientific knowledge mentioned by McLaren has certainly a lot to do with this scenario of devaluation of non-epistemic aspects of NOS, and the positive role of "historicising" science in the teaching of NOS has already been explored by many (including Aragón, Acevedo-Díaz and García-Carmona in their article).

[1] "(…) a confusion that empiricism is politics-free, that the canon is apolitical, ahistorical, and acultural" (Barton 2001, p. 857).

However, most research in the field still uses HOS to address mainly epistemic and empirical aspects of NOS, as seen for instance in McComas (2008), Rudge et al. (2014) and others also cited by Aragón, Acevedo-Díaz and García-Carmona. Thus, even though contextualising and "historicising" scientific development, HOS is very often employed as a guide to the understanding of the progress or changes in scientific ideas (theories, laws, models, experiments).

HOS has been used in Science Education more closely connected with the Intellectual History field than with the analysis of scientific processes as an integral part of economy, politics, culture, social issues. The latter approach, which aims at extending studies of scientific knowledge beyond the history of ideas and towards its sociological analysis as a product of the culture in which it is (was) developed and operates in (Kelly, Carlsen and Cunningham 1993), points towards the type of "historicisation" originally advocated by McLaren.

In their article Aragón, Acevedo-Díaz and García-Carmona adopt this sociological approach to HOS in order to promote discussions about the non-epistemic aspects involved in the historical case of Semmelweis and childbed fever. One important aspect of their perspective about this non-epistemic dimension is, however, how they sociologically conceptualise it (Table 1 in their paper) in terms of "internal" and "external" factors to the scientific community. The "external factors to scientific community" are approached more as factors that are imposed by the external world on the way scientific work is carried out than as twofold relationship between science and this "external world". Here, there seems to be a distinction between science (internal) and society (external), with less attention to how the former is deeply entangled in the latter.

This relationship between science (scientific research and scientific knowledge) and society is more complex and maybe not as clearly demarcated as "us" (science) and "them" (society) as some of these internal/external non-epistemic factors propose. These "internal" practices of the scientific community should not be dissociated from a larger community of social practices, where science is not separated and differentiated from society, but an active actor within it, as pointed out by McLaren: "(…) a powerful sociohistorical analysis of how dominant discourses of science work to serve the interests of the powerful by masking their claims in a neutral view-from-nowhere position." (Barton 2001, p. 857).

Under this approach that does not separate "internal" and "external" non-epistemic aspects of NOS, but understands them as inherently part of social practices, other relevant characteristics of NOS can be explored beyond those conceptualised by Aragón, Acevedo-Díaz and García-Carmona in their Table 1, such as: exploration and exploitation of local knowledge; the role of nature and natural resources in the scientific development; intellectual property and commercial aspects of scientific development; the global and long-term aspects of scientific work; power struggle and social justice issues related to scientific development.

My research about NOS teaching at a secondary school in London explores the possibilities of discussing these non-epistemic aspects alongside the teaching of regular topics from the national science curriculum under a more holistic perspective, in which these "external" and "internal" factors are seen as integral to scientific practices. Informing the development of these teaching and learning activities there is a specific approach to the use of HOS in teaching about NOS that goes beyond an external/internal perspective: an intercultural and dynamic perspective about the development of modern science, or an "intercultural model of HOS"—inspired by Deborah Pomeroy (1994) and Sundar Sarukkai (2014).

This model is based on the "Global History of Science" studies (see Roberts 2009; Elshakry 2010; Fan 2012), which are closely connected with the field of Post/Decolonial Science and grounded on the argument that modern Western Science is in fact a product of exchanges and collaborations between different cultures, and of the circulation of diverse types of knowledge around the world, all promoted by historical and geographical contexts (such as the trade in the Silk Road, and the European colonising and imperialist projects). This field of HOS touches on intercultural and non-epistemic aspects involved in the production of traditional scientific knowledge:

- "How was science consolidated as a form of intellectual property as a result of global processes?
- How has the globalization of cultural forms impacted on the placement of science in the global? What is the relation between the globalisation of science and imperialist science?
- What pathways has science travelled through, and can this be elucidated in relation to the pathways taken by archival and material remains? How did science become bound to empires and nations, and how have global narratives been missed by past scholars?" (Exploring traditions n.d.)

When reflecting about these questions, there are many possibilities presented by the intercultural model to the teaching of non-epistemic aspects of NOS and the integration of its "external" and "internal" dimensions. Its potentialities reside in the fact that the whole use of HOS in science lessons is now informed by notions of collaboration, negotiation and adaptation of scientific knowledge, exploitation of and power-struggle regarding natural resources and knowledge, ethical, economical and political aspects of science, among many others. It is also important to highlight that the choice of using this intercultural HOS model in the teaching of NOS leads to a scenario where explicit discussions about non-epistemic aspects are equally (if not more) important than epistemic aspects. Since the whole construction and narrative of the activities adopts a view of HOS that is mainly informed by non-epistemic aspects of science, it is expected that these will be an integral part of the discussions carried out with the students.

According to Sarukkai (2014), this approach can also bring a more diverse view of science to science lessons, challenging traditions in HOS that "led generations of students in non-Western societies to believe that their cultures have had no contribution to the science of the modern world" (Sarukkai 2014, p. 1696). Furthermore, it tackles the important issue of social justice raised by Angela Calabrese Barton in her mentioned interview with Peter McLaren (Barton 2001, p. 853):

> I can link your point about distancing science from class interests to, on the one hand, how we 'teach' about developing countries in science class. The rare moments when developing countries are described in typical science textbooks tend to be in relation to disease and pollution (i.e., the typical biology textbook picture of the poor African woman with a goiter). The sad parallel is that, on the other hand, I can link this very example to how little mention (or no mention) is given in these same texts to how these poorer countries often serve as the first clinical test beds for new drugs.

In the next section, I will present representative results from my research on NOS teaching using this intercultural model. It is my aim to illustrate the possibilities of this more holistic and global approach towards the teaching of non-epistemic aspects of NOS and

how it can ease their integration with epistemic aspects and also with the regular content from the national curriculum.

An intercultural approach to NOS teaching: insights from the classroom

My investigation about the possibilities offered by this intercultural model of HOS to the teaching about NOS is being currently carried out at a multicultural, state secondary school in London, U.K. in collaboration with one science teacher (teacher F). This experience involves the development and teaching of lessons related to specific topics from the English national curriculum (such as Medicines, Magnetism, and the theory of Evolution), incorporating discussions about epistemic and non-epistemic aspects of NOS under a historic-intercultural model.

The groups of lessons developed under this intercultural model were taught as substitutes of the ones usually taught by teacher F, and participant students (n = 27) were aged 12–13 (year 8 in the English educational system) and enrolled in one of this teacher's science classrooms. Throughout this investigation, data was generated through audio-recordings of my meetings with teacher F, classroom observations during the teaching of each group of lessons/topic, students' diaries written at the end of each lesson, and students' concept maps developed at the end of each topic. My approach towards this data was aimed at understanding the opportunities and constraints offered by this intercultural model to the teaching of topics from the regular science curriculum, with a specific focus on how NOS is being integrated into these lessons.

The first group of lessons developed and taught under this model was about the topic "Medicines", which, according to the English curriculum for the participant students' age group, should encompass the themes of drug trials and animal testing. The sound scholarship in the field of HOS about medicines, uses of natural resources (Natural History), and drug development and trials was then translated into an account inspired by the global approach towards HOS, being transformed into a lesson plan. In order to include not only intercultural discussions about HOS/NOS, but also the content expected by the official specifications, this lesson plan emphasised the development and circulation of medical knowledge and it was expected to last a total of four lessons (between 4 and 5 h), as detailed by Table 1:

Non-epistemic aspects of NOS are operationalised within this lesson plan, being an intrinsic part of the narrative built throughout the four lessons. This sequence is based on a global narrative about the development of knowledge about medicines and how this knowledge expanded from local to global usage, and how this expansion was/is intrinsically connected with economic, social and political encounters (and exploitation) between different communities, also involving the following aspects: exploration and exploitation of local knowledge; the role of nature and natural resources in the scientific development; intellectual property and commercial aspects of scientific development; the global and long-term aspects of scientific work; power struggle and social justice issues related to scientific development.

The incorporation of these aspects into the lessons followed points regarding the teaching of NOS highlighted by Aragón, Acevedo-Díaz and García-Carmona, such as time dedicated to explicit discussions about NOS. For example, when discussing cases of historical medical practices in different cultures, the teacher asked students questions

Table 1 Overview of the lesson plan for the Medicines topic

Lesson	Topic (content or NOS)	Activities
1	Natural resources Medicines (active ingredient, extraction, natural versus artificial) Scientific claims (testimony and evidences) Collaborative and collective nature of the scientific work	Introduction to the topic (cards about early historical contexts—Egyptians, Chinese, native Americans, Arabic, Indian)—in groups Sharing information from the previous cards + teacher talks about naturalist travels and their impacts on medical practices (natural resources in science) Compare and discuss herbal and conventional medicines (task 1)—in groups Open debate about task 1 (collecting evidence, claims, testimony, natural v artificial) Task 2 (homework): research about a traditional plant and how it is used by a different culture (based on discussions about task 1)
2	Medicines (active ingredient, extraction, natural versus artificial) Socio-cultural influences in science Development of medicines (natural resources, animal/human testing) Environmental issues and intellectual property in science Ethics and economics in science	Peer review + discussion about task 2 Teacher introduces modern techniques of drug production (natural v artificial, active ingredient) Video about biodiversity and drug production Task 3: biodiversity/native knowledge and drug production—in groups
3	Development of medicines (quality control and animal/human testing) Experimental design in science (fair testing, double blind, placebo) Socio-political aspects, ethics and controversies in science	Teacher introduces next stages of drug production (animal/human trials, thalidomide) Debate about drug trials (Ebola epidemic and animal testing)—task 4 Task 5 (homework): investigate the future of drug production
4	Development of medicines (quality control and animal/human testing) Vaccines Scientific claims (testimony, evidence) Socio-cultural influences, ethics and controversies in science	Brief open discussion about task 5 Talk about the history of vaccines (historical case—Smallpox in different societies) and what they are (including MMR case) Task 6: Debate about anti-vaccination movements

such as "how did people learn about that?", "how did this knowledge arrive here in Europe?", "why was it so important for other people to learn about that?" and "do you think this is good? Why? Is there any bad side to that?"

The majority of these discussions about NOS were informed by group or individual tasks carried out by the students in order to bring authentic contemporary and historical examples related to the development of medicines. In their first homework, for instance, they were asked to research about an herbal medicine: how it is/was used by a different culture, and if and how it is used as a source of active ingredient in conventional (commercial) medicines. Among the examples brought by them in the following lesson (lesson 2) there were: bark from mahogany trees to fight malaria in Ghana; ginger to cure nausea and as anti-bactericidal in India; Indian snakeroot for high blood pressure; mushroom tea for skin rashes in Kosovo. Then, when presenting this homework, students were stimulated by teacher F to think about the follow-up questions:

> Teacher F: Right, do we think this is a good thing? [using knowledge about natural resources to produce conventional medicines] Hands up if you think it's a good thing that we share this information [the whole classroom put their hands up]. Ok, hands down. Are there any bad sides to it?
>
> Student A: It might not be reliable; they might not have seen the cure in person.
>
> Teacher F: Ok, interesting.
>
> Student B: I was gonna say, because we talked about raids, and raids happen, they can barge into the country and take things, so like most of the remedies are gone. So that's another way it can spread, through raids. Or they can sell it for money, so they give it to different countries.
>
> Student C: Also, like some people, you know, they cut the trees down and they don't plant new trees and stuff. So they will cut it off and then leave it like that. So for the cure for malaria now it's difficult to find the tree.
>
> Teacher F: Ok, so you're talking specifically about the mahogany tree, which has been over-farmed. Is that what you mean?
>
> Student C: Yeah!

While discussing the question proposed by teacher F regarding the examples from their homework, students talked about important environmental aspects connecting the exploitation of natural resources and the production of conventional (commercial) medicines, including aspects related to biodiversity and the exploration of the land. It is also worth noticing how student B, when evaluating the spreading of knowledge about local/traditional medicines also brought to the lesson the financial aspects involved in the exploration of natural resources. Further along this same discussion, teacher F would follow up from student B's idea and ask them to think about other financial costs in the production of conventional medicines. Student A, for instance, talked about quality control and testing as costly steps that needed to be done in order check the effectiveness of these products, something that she had already previously alluded to in the extract above.

An important reflection about the nature of quality control in science arises from student A's answer: is it a purely epistemic aspect of NOS (like "role of experimentation in science" and "research designs and experimental results" aspects in Aragón, Acevedo-Díaz and García-Carmona's work), or is it a case where it becomes difficult to distinguish the epistemic from the non-epistemic aspects? Since quality control and its relationship with the production of scientific knowledge and the social uses of this

• "Scientists learn from each other to improve their knowledge." • "I learnt more about global and ancient medicine and how medicine has grown due to trading." • "I learnt that people from different countries shared cures for illness. This helps in science as today scientists can study the cure and create new ones." • "I learnt that there are many cures but we do not know what they are due to deforestation."	• "It takes long to process the drugs and it comes from many different places." • "I learnt how long it takes for drugs to be released and how long of a process it is." • "You have to back up your discovery with evidence to be believed." • I learnt why scientists would fake results and why people think vaccines are dangerous." • "I learnt that people have many different views on vaccines."

Fig. 1 Examples of quotes about NOS from students' diaries (during the lessons)

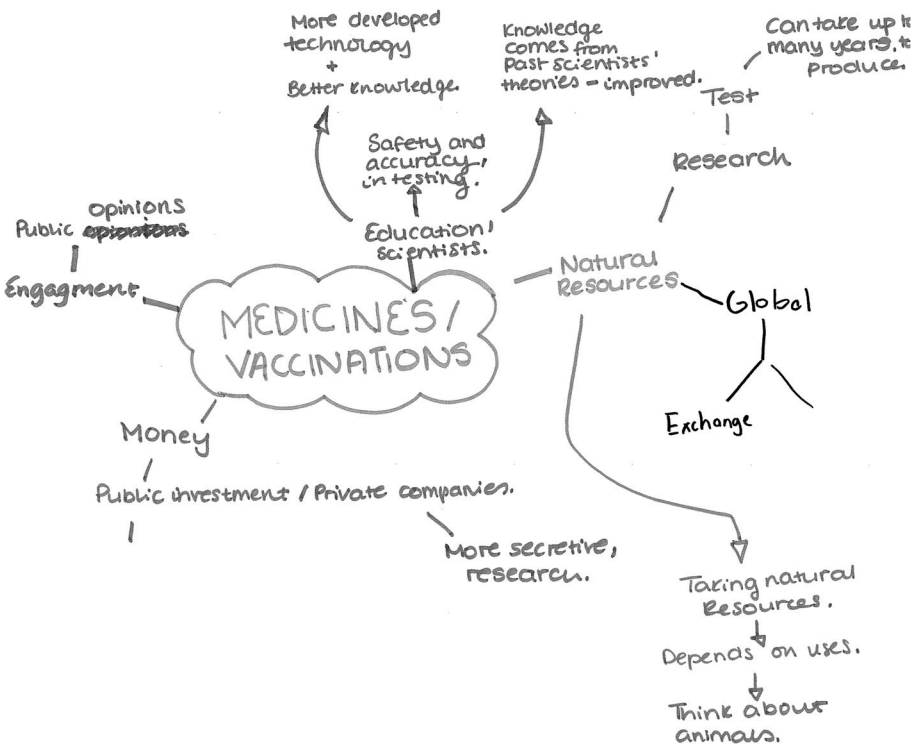

Fig. 2 Group concept map on Medicines (end of the topic)

knowledge are normatively regulated, is the line between epistemic and non-epistemic aspects always so clear? During this investigation, the more holistic and global approach towards NOS teaching allowed for an interdependent and organic connection between epistemic and non-epistemic aspects involved in the production of knowledge about medicines, blurring the line between these different aspects and bringing them closely together.

The impact of these lessons specifically on students' engagement with NOS aspects, as seen in the previous extract, was also investigated through diaries written at the end of each

lesson guided by the question "what did you learn today about how science and scientists work?" (Fig. 1), and group concept map developed at the end of the topic (Fig. 2).

When analysing students' diaries (Fig. 1) and concept map (Fig. 2), we can see how different ideas about NOS were operated by the students during their thinking about this topic: the use of natural resources (through research and global exchanges); knowledge-related ("education, scientists"), public engagement ("public opinions") and ethical aspects behind the production of medicines; the collaborative nature of scientific enterprise—all ideas that were part of the lesson plan and explicitly discussed during the lessons observed. Looking closer, we can see students' thoughts about how money is related to science and the question of public and private investments; how medicines development is dependent on natural resources and how it can have impacts on nature ("think about animals"); how this process is based on long-term and costly research; how testing is an important part of this development to ensure safety and accuracy; how previous knowledge, and exchange of knowledge between different people are also relevant to the development of better and safer drugs; and how this whole process is also subject to the influence of public opinion and ethical decisions.

By adopting the proposed intercultural model, talking about science and its nature in the case of this curricular topic became an intrinsic part of the lesson and, with the help of contextualised work and follow-up questions, non-epistemic aspects of NOS were explored by the teacher in an explicit way. Equally important, this model can also influence how the relationship between science and the "external" world will be portrayed, and enable the inclusion of some NOS aspects that are rarely discussed in school science, especially those related to social justice, environmental issues, exploitation of natural resources and native knowledge, as shown for the Medicines topic.

In this scenario, a defence of the introduction of non-epistemic aspects into debates about NOS needs to take into account the different manners in which this can be done, and the different views of science, its nature and science education that are behind these proposals. While both the Semmelweis case employed by Aragón, Acevedo-Díaz and García-Carmona and the lessons on Medicines developed in my own investigation addressed important non-epistemic aspects of NOS, there is a clear contrast between our approaches to HOS (local versus global, European/Western versus intercultural, respectively), which will most certainly influence participants' views, for instance, on diversity, colonialism and social inequalities connected with scientific work.

Final thoughts

This article aimed at exploring the Aragón, Acevedo-Díaz and García-Carmona's discussion about the teaching of non-epistemic aspects of NOS. While their advocacy of the inclusion of these aspects into the teaching about NOS is relevant and refreshing in a field that tends to focus mainly on inquiry and epistemic aspects of science, my goal here was to expand the debate around these non-epistemic aspects, with special attention to how they have been conceptualised and operationalised by different models. By using results from my classroom-based research on NOS teaching at a secondary school in London, I tried to show how more holistic and intercultural approaches towards historical cases can broaden the 'list' of non-epistemic aspects being incorporated into science lessons and promote an understanding of scientific practises as integral to general social practises.

Going beyond these reflections about NOS, the results from this experience also seem promising in terms of students' interactions with the tasks and discussions proposed, since they were constantly seen responding to teacher F's questions and stimuli, as exemplified by the extract analysed here. Their often active work with the proposed tasks, including the homework, also helped with the development of the lessons and with the continuous generation of ideas and topics for the follow-up discussions, as also seen above. According to teacher F, students at this school are not very used to having science homework, so the fact that at least half of the group (usually around 15 students) worked on both homeworks indicates a positive engagement with these tasks.

This type of work, however, is not easy. Firstly, transforming historical scholarship into lessons around a science topic is not a simple or straightforward process, especially when adapting and bringing historical cases and examples to school science practices and expectations, as argued by other researchers such as Dietmar Höttecke and Cibelle Celestino Silva Silva (2011), and Thaís Cyrino de Mello Forato, Roberto de Andrade Martins and Maurício Pietrocola (2012). In this study, even though the intercultural model enabled the adoption of a more holistic approach towards HOS, aiding the teacher in bringing together learning about the content and about NOS during his lessons, the question of time available for such complex and discussion-based science lessons still impacted our work.

Despite my previous training in the field of HOS and my experience in working with primary historical sources, the intercultural nature of my approach during this investigation exposed how the field is still struggling with the Global History model discussed earlier. Even if the historical scholarship about the topic can be considered well developed and abundant, it still lacks this global perspective that connects the construction of scientific knowledge in a larger scale, bringing together different cultures, societies, and temporal, economical, political and social contexts. Thus, more research on the fields of HOS and NOS teaching is needed if we aim at expanding the possibilities available for science teachers to integrate discussions about NOS into their lessons, especially if related to non-epistemic aspects, which are still largely disconnected from curricular materials.

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