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"It's a lot of people in different places working on many ideas": Possibilities from global history of science to Learning about nature of science

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Abstract

This article describes a teaching experience at an year 8 classroom (students aged 12–13) in a state secondary school in London, UK that aimed at widening learning about nature of science (NOS) with the input from the field of Global History of Science (HOS), which looks at science as a product of material and cognitive exchanges, appropriations and collaborations. Teaching and learning plans (TLPs) informed by this historical framework were developed by the researcher and one science teacher to integrate NOS teaching into fours topics from the national science curriculum in England (Medicines, Magnetism, Evolution, and Earth's resources). These TLPs were taught by the participant teacher to his year 8 classroom (26 boys and girls of mixed-abilities) throughout one school year, and the researcher investigated the impact of the global HOS framework on widening students' views about NOS. Data were collated with the help of students' NOS diaries, group mind maps, classroom observations, and an open-ended NOS questionnaire applied at the start and end of the school year, complemented by participant students' grades in their end-of-year exam. Main findings point to the widening of participant students' views about NOS and, more specifically, about underexplored relevant social-institutional aspects of scientific development, such as diversity and intercultural collaborations and exchanges, exploitation of natural resources, financial, ethical, and political aspects around scientific work. Students were also generally successful in re-applying NOS ideas explored in one TLP to other TLPs and scientific contexts, hinting to the importance of employing overarching narratives (such those promoted by Global HOS), linking different scientific development, when planning the integration of NOS into the school science. Results also show that NOS was integrated into content teaching without negative effects in students' exam grades.

KEYWORDS

curricular materials, diversity, global history of science, nature of science

1 | INTRODUCTION

While several authors argue that History of Science (HOS) has the potential to promote discussions about nature of science (NOS) in school science (Abd-El-Khalick & Lederman, 2000; Allchin, Andersen, & Nielsen, 2014; Matthews, 1994), some of these approaches have been recently questioned (Erduran, 2014; Gandolfi, 2019a; Ideland, 2018; Sarukkai, 2016), especially in relation to the types of historical examples used in most teaching resources. With most of them based on very specific cultural-geographical contexts (e.g., European developments) (Erduran, 2014; Ideland, 2018; Kelly, 2018) and on epistemic aspects (Allchin, 2020; Aragón-Méndez, Acevedo-Díaz, & García-Carmona, 2018), relevant features of scientific development (e.g., collaborations and adaptation of knowledge; exploitation/disputes about natural resources; political, financial and ethical issues) remain underexplored in school science. After decades of experiences with NOS teaching, some argue that we ought now to expand these proposals with more diversified narratives about science (Allchin, 2020; Aragón-Méndez et al., 2018; Erduran & Dagher, 2014), bringing a wider range of NOS aspects to science teaching and learning.

In this article, my goal is to contribute to this call by exploring an experience at a secondary school in London, UK around the inclusion of NOS into regular science lessons under a more historically and culturally diverse approach informed by a specific area of the HOS field: “global history of science” (Fan, 2012; Sarukkai, 2016). By describing a yearlong study carried out in partnership with a science teacher in his year 8 classroom (students aged 12–13), I will examine how this approach can expand the integration of NOS elements into science lessons, while also linking NOS and regular science content.

2 | BACKGROUND TO THIS STUDY: NOS AND HOS IN SCHOOL SCIENCE

Historically, studies in Philosophy of Science have been strongly implicated in the reflection about the production of scientific knowledge—often called "nature of science"—(Lederman, 2007) and subsequent movements in the Science and Technology Studies (STS) field from the 1970s onward have also impacted this conceptualization (Allchin, 2020; Collins & Pinch, 1998; Erduran & Dagher, 2014; Hodson, 2014). Links between science and societies and how scientists work as a group then became relevant to reflect about NOS, including how these social features relate to epistemological ones (e.g., peer review and epistemic security, theory construction). Inevitably, these contemporary perspectives on what NOS is resulted in debates about what it can specifically bring to school science.

The main argument for NOS in school science is that learning about science as a "process" is needed for grasping the complexities of a field that has great impact worldwide (Abd-El-Khalick & Lederman, 2000; Allchin, 2020; Ideland, 2018). Exploring NOS with students then has the potential to promote a more critical and realistic view of science (e.g., affordances and limitations). Recent issues with anti-science feelings and "alternative facts," for example, can be linked to a lack of understanding of "how science works" (Allchin, 2020).

Nevertheless, there are different views on how NOS should be conceptualized for school science and the most cited one is by the "Lederman group" (Justi & Erduran, 2015, p. 1). This view advocates teaching NOS—that is, the "values and epistemological assumptions underlying scientific knowledge and its development" (e.g., tentative and theory-laden, etc.)—and "nature of scientific inquiry" (NOSI)—"activities related to the collection and interpretation of data, and the derivation of conclusions" (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002, p. 499). Others, for example, Erduran and Dagher (2014) and Allchin (2020), argue for the integration between "NOS" and "NOSI" as part of a "holistic view of NOS": with content, scientific inquiry, epistemic and social dimensions being intrinsically intertwined. Under this approach, NOS would encompass linking purposes of science, nature of its knowledge (epistemic dimension) and its status as a social enterprise (social dimension), exploring: role and status of scientific knowledge generated by scientific inquiry; the modeling that attends the construction of scientific theories; social and intellectual circumstances of their development; how scientists work as a social group; the ways in which science impacts and is impacted by the social context; and so forth (Aragón-Méndez et al., 2018; Driver, Leach, Millar, & Scott, 1996; Hodson, 2014).

In general, these connected and dynamic perspectives about NOS linking epistemic and social-institutional aspects seem promising to its inclusion into school science: this approach can ease its integration with scientific content, with both seen as part of a wider process of knowledge development (Martins & Ryder, 2015), a position that I will adopt in this study. The choice between different views of NOS does not, however, address the question of "how to" include it in school science. There is not only one way of engaging with NOS, but different investigations (e.g., Deng, Chen, Tsai, & Chai, 2011) have explored useful strategies, such as: the more beneficial impact of explicit NOS teaching (i.e., promoting concrete reflections about NOS as it appears in the lesson) against an implicit approach (i.e., NOS aspects as by-products and not as planned outcomes of a lesson); "Inquiry activities" (engagement with cases of scientific research and hands-on activities); "Contemporary cases" (study about a contemporary scientific topic, for example, socio-scientific issues); and "Historical cases" (Allchin et al., 2014).

In this study, an explicit historical approach was chosen to inform the design of NOS resources, since HOS has the potential to help students learn about science as a complex and intricate enterprise (Matthews, 1994), about its tentativeness and errors, sociocultural features (e.g., collaborations, funding), and about its methodological pluralism (Allchin et al., 2014). In addition, HOS resources can ground a more balanced context-based teaching about both epistemic and social-institutional NOS aspects, the "holistic perspective" of NOS recently asked for by, for instance, Allchin (2020) and Aragón-Méndez et al. (2018).

Nevertheless, while many argue that HOS can facilitate this integration of NOS into school science, some of these ideas have been recently questioned (Ideland, 2018; Jegede & Aikenhead, 1999; Kelly, 2018; Sarukkai, 2016) around the types of historical contexts employed in teaching resources. Hodson (1998) talks about how most of these resources tend to reduce or ignore historical contributions by different contexts other than European ones. For instance, among 50 HOS-based teaching resources designed by two recent projects,[1] only three included examples from non-European or non-USA communities/scientists. Ideland's (2018) recent study of Swedish science textbooks yielded similar results on the cultural/geographical origins of the examples of scientific work used in these materials.

Some authors (Erduran, 2014; Gandolfi, 2018, 2019a; Ideland, 2018; Sarukkai, 2016) argue that this sole focus on European examples can propagate an incomplete and unrealistic image of science as purely a European endeavor, and recent empirical studies (Christidou, Bonoti, & Kontopoulou, 2016; Gandolfi, 2018; Gurgel, Pietrocola, & Watanabe, 2014) on students' images of science and scientists seem to support this argument: their findings show that despite living in mostly multicultural societies, students from diverse backgrounds still link historical and contemporary scientific work with "white European" and "lone genius" profiles. This lack of diversity when portraying scientific work and scientists (a "selection bias") can consequently propagate an image of scientific work as "for the few," individualized and purely epistemic, missing out on the complexity, limitations, implications, and especially, on the sociocultural aspects of scientific practices (Allchin, 2020; Ideland, 2018). As a result, the chances of actually adopting a "holistic approach to NOS" are severely constrained, since how can an approach be holistic if cases/examples come very few and limited contexts?

These authors have then been calling for a diversification of ideas/cases when teaching about NOS through HOS. Their rationale is that a more diverse approach to historical narratives can foster a wider understanding of who scientists are and how they work, including cross-cultural interactions, pluralism and fluidity of scientific practices, exposing "the many often ignored 'faces of science'" (Allchin, 2020; Erduran, 2014, p. 106). That can inform a more holistic/comprehensive portrayal of how science is done in diverse contexts, bringing forward some NOS elements (especially social-institutional ones) that are crucial to our understanding of current socio-scientific realities (e.g., knowledge exchanges in an era of global health and climate crisis), as argued by Allchin (2020).

Nevertheless, very few accounts of empirical experiences can be found in the field that take into account this more diverse approach to HOS-based NOS teaching at school level (e.g., Alcantara, Braga, & van den Heuvel, 2020; Lee & Kwok, 2017). As mentioned above, most resources available still focus on limited cases, usually from European or USA history. Thus, to contribute to this call for more breadth and diversity in NOS teaching through HOS, I will explore here an experience at the secondary school level that took a global stance when looking at science. My position is that scientific development is a rich, complex, and culturally, politically and socially diverse endeavor and that NOS teaching should reflect this richness and complexity if it aims to be holistic and transparent about to how science works. My goal in this article is then to explore whether and how scholarship from a specific area of the STS field—Global HOS—can foster students' engagement with NOS in all this intricacy and diversity.

3 | THEORETICAL FRAMEWORK: GLOBAL HOS

Among diverse perspectives in the STS field that have recently emerged from more sociologically-informed research, there is the “Global HOS” (Fan, 2012; Patiniotis, 2013), which is grounded on the idea that modern science is a product of exchanges (forced or not) between different communities, societies and people throughout our history - i.e., collaborative and exploitative networks (e.g., Silk Road and Great Navigations). This area is interested in questions such as “how was science consolidated as a form of intellectual property as a result of global processes? What pathways has science travelled through?” (Exploring traditions, n.d.).

Fan (2012, p. 251) argues that “[i]nstead of looking at science and technology as products in a particular nation or civilization, the main focus of Global History of Science is on the transmission, exchange, and circulation of knowledge, skills, and material objects”. It can then avoid epistemological issues posed by extreme relativistic approaches by not adopting a comparative course to studies about science: instead of focusing on similarities and differences among knowledge systems, it understands science as a product of cultural and economic exchanges (forced or not) among these systems (Patiniotis, 2013; Sarukkai, 2016).

Global HOS works with a “big picture” approach to scientific development, where micro and macro studies bring together the best of both worlds: while a micro perspective focuses on localized, specific scientific achievements/contexts, the macro perspective establishes connections between this particular case and its social, cultural, political, and economic global background (Orthia, 2016). This does not mean understanding scientific knowledge as global (a “universalist” perspective) but seeing its development as a result of global links. This fosters a “more pluralist, more historicist, more localised, less universalist picture of science” (Orthia, 2016, p. 363), while also recognizing the limits of these global collaborations and the place of colonization; as a result, science is portrayed as a product of cultural interactions across the world rather than a solely “Western” endeavor (Lee & Kwok, 2017).

But what can this specific approach to HOS bring to school science? In this article, I will argue that Global HOS can be useful to address recent concerns about the narrowness of proposals for NOS teaching (i.e., focus on very few epistemic aspects and examples of scientific work), as discussed in the previous section. In addition, it can help circumventing some limitations of the use of HOS in NOS teaching and learning, such as concerns about the “distance” between these specific contexts and contemporary students' realities (Allchin et al., 2014), exactly through its more global stance toward scientific development, always looking for the bigger picture behind the selected stories. Similarly, by engaging with both “macro” and “micro” perspectives about contexts of scientific work (Orthia, 2016), it can also facilitate the “transfer” of NOS ideas (Khishfe, 2013) explored as part of a specific science content/subject (e.g., Medicines) to other scenarios/cases (e.g., Magnetism) by fostering links between these context-specific ideas/cases and wider scientific practices and realities.

Thus, here I will examine a teaching experience based on Global HOS at an English secondary school to explore whether and how this approach can help widening students' understandings of scientific development. To inform this study, I devised a conceptualization of Global HOS for school science that I call “intercultural model of HOS” (Gandolfi, 2019a). This model attempts to transpose research, ideas and findings from Global HOS to the realities of school science and curricula, and it involves teaching scienceas a product of exchanges among different communities (i.e., “intercultural”) in diverse historical moments. It understands that there is a widely spread way of "doing science", but it also acknowledges intercultural aspects around scientific development through the lenses of post/decolonial studies (Patiniotis, 2013). For instance, when teaching the topic of Magnetism, this model could link uses of magnetic properties by different communities in history to how material and knowledge exchanges among them enabled technological development (e.g., compass) and global expansion. In turn, this knowledge about the compass and Earth's magnetic properties ended up fostering even more circulation/exploitation of knowledge/resources (e.g., access to medicines, minerals) (Gandolfi, 2019a, 2020).

The potential of this model to school science resides in the fact that the exploration of NOS and content through HOS is now informed by notions of collaboration, negotiation and adaptation of knowledge, exploitation of natural resources, and ethical, financial and political aspects. Thus, by being based on a global perspective, it brings the complexity and plurality of science to the front, while also addressing epistemic and non-epistemic NOS elements as intrinsically linked and inseparable from each other. As argued by Allchin (2020), Aragón-Méndez et al. (2018), Erduran and Dagher (2014), and Ideland (2018), this holistic approach to epistemic and socio-institutional aspects and engagement with some underexplored features of scientific development (e.g., politics, economy, trade and colonization) is crucial to understanding the complexity of our current realities and of several socio-scientific concerns affecting us all, including young students, such as the COVID-19 pandemic and the global climate crisis.

Nevertheless, resources using a similar approach when selecting and creating narratives[2] about NOS are still scarce, as reported by Erduran (2014) and Ideland (2018). Most research is still occurring at a "theoretical level," with not many instances of their transposition into empirical studies. One of the few examples in the literature adopting a similar approach (although not calling it "intercultural model of HOS") is the experience described by Lee & Kwok (2017, p. 162) of teaching about vaccines to students aged 17–18 in Hong Kong under a cross-cultural and knowledge exchange perspective, with positive results found around "students' rich, diversified and nuanced characterization of science".

Therefore, in this article I will describe and analyze a teaching experience in which a participant teacher taught four official topics from the national curriculum for Science in England aided by resources grounded on this proposed intercultural model of HOS. While this experience is linked to a larger collaborative project (Gandolfi, 2019b, 2020), here I will specifically explore the effects of these resources on widening his students' ideas about NOS.

4 | METHODOLOGY

4.1 | Research approach and objectives

This study is part of a larger doctoral project that first explored the regular teaching and learning of NOS in mainstream state secondary schools in the London, UK area (Gandolfi, 2017, 2019b) and that, at a second stage, promoted a collaborative experience between me (researcher) and one science teacher at one of these schools. In this second stage of the project, the participant teacher and I worked on a researcher-practitioner partnership, already explored elsewhere (Gandolfi, 2020), that aimed at developing and teaching four "teaching and learning plans" (TLPs) based on the intercultural model of HOS to help this teacher to include NOS into his regular science lessons. In this article I will specifically explore, under a qualitative-interpretive approach (Scott, 1996), the impact of these four TLPs on participant students' views about NOS. These resources were taught by the participant teacher over one school year and my aim during that period was to investigate the following question: "In which ways can the teaching of science through the intercultural model of HOS contribute to widening participant students' views of NOS?"

In addition, while some authors (e.g., Hodson, 2014) advocate NOS teaching alongside regular content, as idone in this study, others (Clough, 2018; de Berg, 2014) criticize the lack of accounts about effects (especially negative) of these experiences on students' content learning due to competition for space in the curriculum between content and NOS. Therefore, my secondary aim in this study was to explore if the inclusion of NOS in these lessons would incur negative outcomes to students' learning of the expected content from the national curriculum.

4.2 | Research setting and participants

The participant school, school A, is an urban secondary state school in London, UK with more than 50% of its 860 students (boys and girls aged 11–18) with English as an additional language. This school was invited to participate for convenience: they have links with my previous research institution via their Initial Teacher Education programme and they are a good representative of a standard state secondary school in the London area (i.e., multicultural, large number of students). Among all science teachers there who participated in the initial exploratory stage, Ian (pseudonym) was invited to take part in this experience due to his interest in improving his practice around NOS teaching. He did not have any prior training in this area and working on the TLPs was expected to also impact his professional development, as explored in Gandolfi (2020). Ian is a Biology specialist, male, White British with 10 years of teaching experience. The participant classroom was his only lower-secondary group in that year (convenience sampling)—a year 8 group of 26 mixed-abilities students[3] aged 12–13 (44% girls, 56% boys),[4] who had two weekly hours of science lessons with him; written consent for participation was obtained from students and their parents.

4.3 | The teaching and learning plans

Four teaching and learning plans (TLPs) were created for the following topics from the year 8 curriculum: Medicines, Magnetism, Evolution and Earth's resources. These topics were chosen for their convenience: Ian had to teach them in that order to that year 8 group. In addition, working with topics from different science subjects would diversify experiences and reflections on the potential of the proposed model for NOS teaching. Each TLP was designed to cover all the content from the year 8 original curriculum (OC) for each topic and relevant NOS aspects selected during our work on these resources; that is, NOS did not replace original content, it was integrated into it. The teaching of each TLP (each topic) lasted 5 hr, similar duration to what is suggested by the OC. Table 1 compares science content and NOS aspects for these topics found in the OC and in the TLPs created in this study.

In the first stage of designing each TLP, a historical narrative was chosen to inform the sequence of lessons for that topic, called by Matthews (1994, p. 71) a "storyline strategy," where "a science topic [...] can be placed in a developing narrative." This strategy enables linking and re-visiting different content and NOS aspects as the lessons advance. Perspectives from the Global HOS field then informed the choice of this overarching narrative for each TLP:

TABLE 1 Comparison of content and NOS aspects in original curriculum (OC) for year 8 science and in the proposed resources (TLPs)

Content (both in the OC and TLP)				NOS aspects				
Medicines	Magnetism	Evolution	Earth's resources		Medicines	Magnetism	Evolution	Earth's resources
Stages involved in the testing of a new drug	How magnets interact	Theory of natural selection	What an ore is	Social and cultural influences in the production of scientific knowledge[a]	TLP		TLP	
		Why species evolve over time	Methods of extracting metals	Relevance of natural resources to production of scientific knowledge (issues of environmental and intellectual property nature)[ab]	TLP/OC		TLP/OC	TLP/OC
Animal testing of medical drugs	Magnetic field diagrams, direction and strength of a magnetic field	Darwin's work on natural selection	How the Earth's resources are extracted	Collective nature of the scientific work, exchanges, collaborations and transmission of knowledge[a]	TLP	TLP	TLP/OC	TLP
		Factors that may lead to extinction	Choices of extraction method for a metal	Relationships between science, ethics, financial systems, politics, and so forth[a]	TLP/OC		TLP	TLP
Case studies of drug testing	Earth's magnetic field	Biodiversity, animals and plant populations	Factors to consider when extracting metals	Scientific claims, evidence and testimony in scientific development[ab]	TLP		TLP	
		Why a species has become extinct	Why certain Natural resources will run out	Experiment, controlled investigation and quality control in scientific development[b]	TLP/OC			
		Biodiversity and ecosystem	Why recycling some materials is important	Relationship (and differences) between science and Technology[b]		TLP/OC		TLP
		Endangered species (meaning)	How Earth's resources are recycled	Observation, evidence and modeling in scientific development[b]		TLP/OC	TLP	

TABLE 1 (Continued)

Content (both in the OC and TLP)		NOS aspects				
	Techniques used to prevent extinction	Science is tentative, creative and does not answer all the questions[ab]		TLP		TLP
	How preserving biodiversity benefits humans	Controversies, disagreements and processes of certification (peer review) in scientific development[ab]	TLP		TLP/OC	
		Relationships between evidence, explanation and theory in scientific development[b]	TLP		TLP/OC	

[a]Social-institutional dimension of NOS.
[b]Epistemic dimension of NOS.

- *Medicines TLP*: accounts about the uses of natural resources in the history of medicines and medical knowledge, including the importance of natural resources to medicines development; local knowledge about natural resources; and how the frequent contacts between different groups fosters exchanges and exploitation of these resources and expertise.
- *Magnetism TLP*: history of the relationship between science and technology in the form of the compass. Building on the Medicines TLP, this TLP was grounded on how knowledge and uses of magnetic materials were exchanged and expanded by the interactions between diverse communities, and how this enabled even more expansion and contact between communities through technological innovations (e.g., compass).
- *Evolution TLP*: historical sociocultural narratives around the processes of species change, collection of evidence and development of explanations for these processes; links between naturalist travels, natural resources, extinction, and the theory of Evolution. This TLP connected ideas previously explored in the Medicines TLPs on natural resources and naturalist travels with Natural Selection, theory of Evolution and biodiversity.
- *Earth's resources TLP*: accounts on metal usage/exploitation in different societies and on the links between these natural resources, environment, and chemical knowledge. This TLP linked to the previous TLPs by exploring the impact of naturalist travels and colonization/imperialist endeavors (e.g., metallurgy in the colonial Americas) on development of chemical and technological knowledge about metals, extraction techniques, and on environmental issues.

In the second stage of designing these TLPs, relevant NOS aspects arising from the historical narratives above were selected to be explicitly explored alongside the expected content, as displayed in Table 1. This selection was informed by holistic views of NOS (e.g., Aragón-Méndez et al., 2018; Driver et al., 1996; Erduran & Dagher, 2014) that advocate a balanced and interlinked consideration of epistemic and non-epistemic aspects. That means that while some NOS elements in Table 1 can be classified as epistemic or social-institutional, discussions, tasks and homework in these TLPs focused on exploring their connections, as opposed to a stand-alone work on isolated, disconnected NOS aspects.

In addition, Forato, de Andrade Martins, and Pietrocola (2012) argue that HOS-based NOS teaching resources should promote connections and comparisons about NOS by using different scientific scenarios and examples. This allows teachers to circumvent possible obstacles posed by students' pre-conceptions about epistemology and HOS by constantly re-visiting NOS aspects and reflecting about their similarities and variations when looking at different scenarios; that way, teachers can identify and further explore misconceptions and students can deepen and rethink their ideas about NOS. To achieve that, an "integrated strategy" (Matthews, 1994) was also used at this second stage to connect different NOS aspects among the four TLPs: when selecting these aspects for each TLP, an effort was made to ensure that some would also be explored in other TLPs (see Table 1), allowing Ian to re-visit several NOS elements with his students over the school year. Figures 1 and 2 below, displaying two sequences of slides used in the Medicines and Magnetism TLPs, respectively, illustrate how these links between different topics were implemented in practice.

These figures exemplify how specific NOS aspects, such as knowledge/material exchange linked to the compass (Magnetism TLP), would already have been explored in other topics, such as in the case of access to natural resources and development of medicines (Medicines TLP). These TLPs were then planned and taught interconnectedly through their shared intercultural view of material and knowledge circulation (as also depicted above in the description

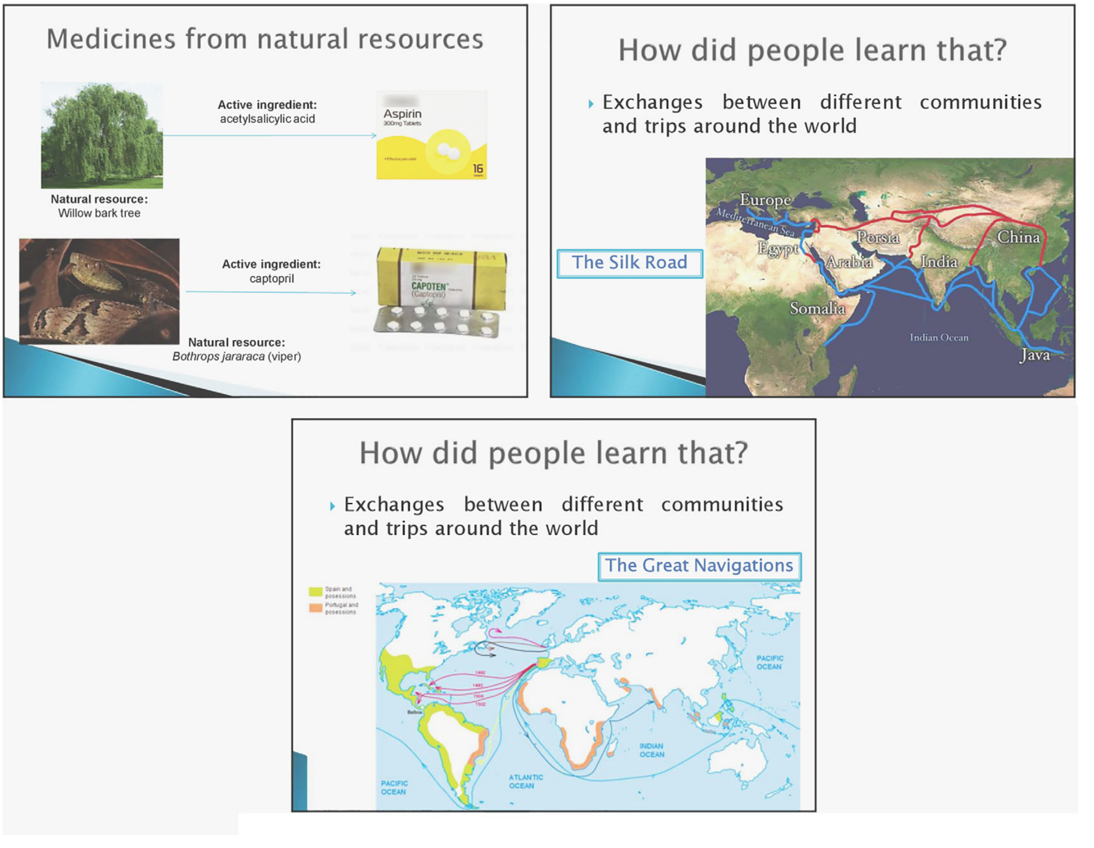

FIGURE 1 Sample of slides from Medicines teaching and learning plan (TLP) [Color figure can be viewed at wileyonlinelibrary.com]

of narratives informing these resources), with the very nature of this perspective—a global look at scientific and technological development—bringing distinct NOS aspects, content and storylines together.

The adoption of these "storyline" and "integrated" strategies then allowed for the design of the TLPs under a "spiral approach" that aimed at addressing Forato et al. (2012)'s suggestion for lessons to be interconnected both "among" and "within" science topics. Classrooms discussions, tasks and homework were linked within TLPs ("storyline" strategy) and NOS ideas were re-visited in the following ones ("integrated" strategy), as exemplified by Figures 1 and 2 above and by the following whole-classroom discussion between Ian and his students during a lesson about metal exploitation and extraction as part of the Earth's resources TLP:

> Ian: How do you think they found out about their [all these metals] existence in difference places?
> Student G: Through trading?
> Student H: Ah yeah, with Medicines [TLP], there was the Silk Route.
> Student I: Yes, with the compass [Magnetism TLP] as well.
> Student J: You can navigate around the world and visit different parts.

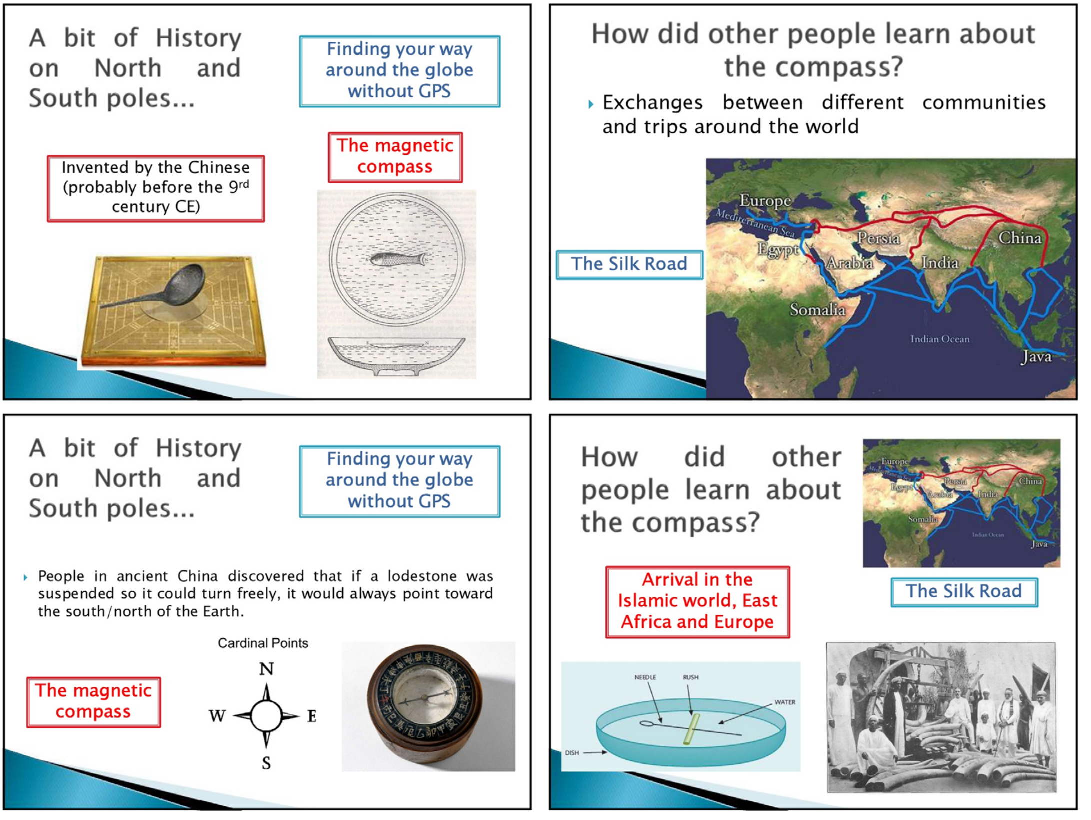

FIGURE 2 Sample of slides from Magnetism teaching and learning plan (TLP) [Color figure can be viewed at wileyonlinelibrary.com]

In addition to planning the intercultural-historical narratives and NOS aspects to be explored in each TLP, different activities—such as direct teaching/slides (as seen in Figures 1 and 2), experiments, debates and homework—were employed in the development and implementation of these resources, all aiming at explicitly connecting content with NOS. In order to explore NOS explicitly as part of these TLPs, follow-up questions about particular cases/tasks/experiments were planned to guide small groups and whole-classroom discussions between Ian and his students. These questions, based on "assessment for learning" perspectives (Black & Harrison, 2004), did not aim to check students if they were right or wrong about NOS or to provide them with "declarative definitions" of a certain NOS idea, but to help Ian to scaffold his students' own conversations and thinking about NOS, from initial thoughts about an examples/task to more complex and well-developed ideas. As argued by Clough (2006) and Martins and Ryder (2015), this explicit question-based and scaffolding-based approach to NOS teaching can circumvent issues around oversimplification, pre-conceptions about science and scientific work, while also promoting the integration of socio-historical themes into content-based lessons.

As an example of this explicit, question-based and scaffolding-based approach, we can look again at the discussion above between Ian and his students about metal exploitation. This is an extract of a larger whole-classroom discussion promoted as part of a task where students had to first explore (in pairs) a set of cards with examples about metals, their properties and historical/contemporary exploitation, and then discuss, as a whole group, the following set of planned follow-up questions: "1. What are the main uses of the metals presented by these cards? 2. Can you think about any other important applications of these metals nowadays? 3. What kind of properties do metals have that make them so important? 4. What is the relationship between using metals, Science and Technology? 5. How were the metals obtained by the communities in your cards? 6. Do you think all metals can be found in all places around the world?". Ian then guided his students through thinking about these questions by interacting with their initial answers, and prompting them to make further connections and expand their ideas, including by linking these with other previously explored cases/examples (e.g., medicines and the compass).

We then co-planned tasks (e.g., experiments, homework), slides and these follow-up questions, designing complete sequences of activities and lessons, each with their specific learning goals around content and NOS. This also included writing teaching notes and providing extra historic-epistemological resources for Ian (Gandolfi, 2020). Tables 2 and 3 exemplify how content, NOS, intercultural-historical narratives, activities, and sets of follow-up questions about NOS came together in the Magnetism and Evolution TLPs.

4.4 | Methods of data generation and analysis

A multi-method approach was adopted to investigate short and long-term links between the TLPs and students' ideas about NOS. These methods and the analysis of the data generated were mainly of qualitative and classroom-based nature (Scott, 1996).

- *Students' diaries about NOS*: short entries written individually at the end of each lesson of a TLP to map links between NOS goals for that specific lesson (see, e.g., Tables 2 and 3) and NOS ideas actually identified by students as learnt in that lesson. Each student was asked to answer: "what did you learn today about how science and scientists work?".[5] 14 complete diaries were produced (i.e., 14 students had entries for all lessons when this task was applied) and quotes from the remaining 12 incomplete diaries were also compiled.
- *Group mind map*: to complement the diaries by mapping links between the teaching of the TLPs and students' learning about NOS, one map about each topic was produced by a group of five students selected by Ian at the end of each TLP. The aim of these maps was not to track changes in students' views about NOS (in a pre/post style), but to investigate which NOS aspects taught as part of that TLP were being identified by students as key ideas arising from their learning about Medicines, Magnetism, Evolution and Earth's resources. For each map (i.e., TLP), a different group of five students (representative of gender and ability distribution in the classroom) was chosen to ensure that all who wanted had a chance to participate while also abiding to time and school's constraints; thus only one group worked in each map. A "mind mapping" session after the last lesson of each TLP was carried out, each lasting 30 min and resulting in one mind map (totaling four). These sessions happened during their breaks and under my responsibility in an adjacent room to their classroom, giving them space to discuss what they would include on the map based on the prompt: "what have you learnt about [TLP topic] with Ian these past weeks?" In the spirit of mapping what they actually got out of each TLP, they were free to collaboratively annotate any ideas (about NOS or content) they deemed relevant and I also encouraged them to link annotations by asking a few generic questions (e.g., "what else did you learn about this?", "how is this connected with that?"). I did not give them any other instructions apart from a brief explanation on mind maps. These "mind mapping" sessions were also audio-recorded to register discussions among these students aiming to complement their maps (e.g., specific conversations about NOS).

TABLE 2 Outline of the Magnetism TLP

Lesson	Content and NOS aspects	Outline of the lesson	Examples of follow-up questions about NOS
1	- Magnetism (force and materials) - Observation and indirect evidence in science - Science is tentative, creative and does not answer all the questions	- Starter: Show picture to illustrate magnetism as a phenomenon (ancient Greece)—"What is happening here?"; "Can we really see what's causing that?" - Introduction to the topic—Cards with different historical observations of magnetism (in pairs). Sharing information about the cards + discussion about observations, indirect evidence and inferences in science - Teacher talks about what magnetism is and about the history of the magnetic materials (loadstone in ancient Greece/Magnesia) - Task 1 (practical): Test different materials for magnetism and discussion on observations, indirect evidence - Teacher talks about types of magnetic materials (based on their results from task 1 as well), and why some materials are magnetic and others not - Task 2 (homework): Magnetic materials at home	*Discussion about introduction cards*: *1. Take a look at your card and discuss it (in pairs). Share what you learned from the card with everybody else.* *2. Is magnetism a phenomenon that we only know of nowadays?* *3. What did people in old times use to do with magnetism?* *4. Thinking about these different examples of uses of magnetism, is magnetism something that we can see? What type of evidence do we have for it?* *5. Is having evidence for something the same as knowing how to explain it?* *6. If magnetism cannot be seen, how do you think people learned about it?* *7. How do you think scientists nowadays go about investigating and learning about things and phenomena that cannot be seen, like magnetism?*
2	- Magnetism and magnets (poles and instruments) - Social and cultural aspects of science (commercial aims, contextual influences, exchange and transmission of knowledge) - Relationship (and differences) between science and technology	- Presentation of homework + discussion about science and technology - Teacher talks about how magnets work (north/south poles) and how the Chinese developed the compass - Teacher talks about the arrival of the compass to the Western world (silk road, navigations around the Indian ocean). Teacher briefly talks about its arrival in Europe and the impact on the great navigations and metal/coal exploration.	*Discussion about task 3*: *Think about the possible impacts of being able to navigate around the world at that time on each of these fields*: *Economy Science & Technology Politics Everyday life*

TABLE 2 (Continued)

Lesson	Content and NOS aspects	Outline of the lesson	Examples of follow-up questions about NOS
		- Task 3: Importance of great navigations to the world (in pairs) + discussion - Brief examples of modern uses of magnets	
3	- Magnetic fields and Earth's magnetic field - Modeling in science - Observation and indirect evidence in science	- Introduction to magnetic fields - Prompts: "Birds migration" + "how does a compass know where to point to?" - Studies about the Earth's magnetic field (e.g., William Gilbert) - Task 4 (homework): Magnetic fields in nature	*Discussion about Earth's magnetic field*: *1. What do we mean by "model of the Earth's magnetic field"? What do we mean by "model"?* *2. Did Gilbert carry out his experiment with the earth itself? How did he model the earth in his experiment?* *3. Think about how Gilbert found out about the Earth's magnetic field. Can we see this magnetic field? How do we know that this field exists?*
4	- Earth's magnetic field - Science is tentative, creative and does not answer all the questions - Observation and indirect evidence in science	- Presentation of homework + discussion: "Can we see the Earth's magnetic field?" - Teacher talks about the northern lights and the sun (observation and indirect evidence, Mary Somerville's experiment on the magnetic nature of light) - Task 5 (practical): Magnetic field with iron fillings and magnetic field patterns	*Discussion about task 4*: *1. Why are magnetic fields so difficult to be detected? What type of evidence do we have for them?* *2. Can we really "see" the magnetic field when we look at the northern lights?*

- *Lesson observations*: I observed all 22 lessons (1 hr each) related to the TLPs to collate data (through note-taking) on how the TLPs were being taught by Ian and how students were engaging with discussions/tasks about NOS. Here my approach was to twofold. First, I wrote a timeline of all events taking place during a lesson using an ethnographic strategy, focusing on who was talking (student, teacher, group of students), what they were talking about (e.g., NOS, content, examples) and for how long, and how the rest of the group was participating in these events. My focus here was on gathering which content and NOS ideas were being explored by Ian and his students and, more importantly, if they were mentioning specific aspects already developed in other lessons and TLPs. That would allow me to examine the effects of the "spiral strategy" on students' engagement with NOS aspects. In addition, I cross-referenced these notes with our plans for each lesson/task (i.e., with the TLPs) against the following rubric: (1) Completion of an original teaching objective/activity (e.g., were all

TABLE 3 Outline of the Evolution TLP

Lesson	Content and NOS aspects	Outline of the lesson	Examples of follow-up questions about NOS
1	- Natural selection and theory of evolution I (development) - Evidence and its uses in science - Collaborative and collective nature of the scientific work - Relationship between evidence, explanation and theory	- Initial discussion on what they already know about natural selection and evolution - Introduction to the topic (cards about early historical ideas on evolution) – In groups + sharing information from the cards - Discussion about the notions of evidence and explanation in science – "How you would go about showing that your explanation is a good one?" - Introduction of the works of Darwin and Wallace ("search for evidence"). Discussion about research on natural selection and evolution - Task 1: Survival of the fittest – In pairs	*Discussion about research on natural selection and evolution*: *1. How did Darwin and Wallace develop their theories about natural selection and evolution? Based on what?* *2. What is the importance of Darwin and Wallace's travels to the development of the theory of evolution?* *3. Can you think about different reasons why the British government was interested in these travels of natural surveyors around the world?* *4. Darwin and Wallace did not originally work together on their theories, but they eventually exchanged several letters and comments on each other's works.* *5. Why is this important to science? How did that help them?*
2	- Natural selection and theory of evolution II (implications) - Social and cultural influences in the production of scientific knowledge - Controversies, disagreements and processes of certification (peer review) in science - Relationship between evidence, explanation and theory - Relationship between science, ethics, economics, environment, and so forth	- Recap of natural selection and evolution ("tree of life" video) - Task 2: Different opinions about the theory of evolution (cards) + discussion - Discussion about evidence and theory (development of theories) - "Evidence for evolution?" - introduction of different post-Darwin case studies (e.g., peppered moth, human evolution, antibiotic-resistant bacteria, extinction) - Examples of different "uses" of evolutionary ideas in society (e.g., eugenics) + discussion - Task 3 (homework): Family tree (organism of choice)	*Discussion about uses evolutionary ideas in society*: *1. Can we say that science and scientific ideas have only positive impacts on society?* *2. Do you think it is good to use science to guide social decisions?* *3. Can you think of any positive example of scientific knowledge being used to guide social decisions?* *4. Are decisions made with the help of science always rational? Why? (think about ethics and about who is making these decisions).*
3	- Extinction and its causes - Relationship between science, ethics, economics, environment, intellectual property, and so forth	- Discussion about task 3: Focus on the future of the chosen organisms—Connection with extinction	*Discussion about video on the history of research about extinction*: *1. What is the connection between "time" and "extinction"? Is it*

TABLE 3 (Continued)

Lesson	Content and NOS aspects	Outline of the lesson	Examples of follow-up questions about NOS
	- Relationship between evidence, explanation and theory - Controversies, disagreements and processes of certification (peer review) in science	- Initial discussion on what they already know about extinction (“what does extinction mean”?) - Video about the history of research around extinction - Task 4: “Threatened, endangered, extinct” (examples of species)—Cards in pairs + sharing with the class - Discussion about causes and local implications of extinction—Global examples - Video: “Causes of extinction” (summary of task 4) - Task 5: “Dinosaurs extinction”—information sheets in pairs + plenary	*usually a short-term or a long-term process?* *2. Did scientists always agree about the idea of “extinction” of species? Why?* *3. What is the importance of fossils to our understanding of extinction?* *4. What is the connection between extinction, and the process of natural selection and the evolution of species?*
4	- Preservation of biodiversity - Relationship between science, ethics, economics, environment, intellectual property, and so forth	- Recap on biodiversity (link to medicines TLP)—What it is, why it's important—Connection with the idea of extinction - Discussion about conservation and preservation of biodiversity (how to do it) - Task 6: “What do we preserve when we aim for ‘biodiversity’?”—The case of the preservation of blue macaws (in pairs) - Discussion (based on task 6) about preservation of biodiversity—“Preserving for what and for whom?”	*Discussion about task 6*: *1. In this case, who is benefiting the most from the scheme proposed?* *2. Are the macaws someone's property?* *3. If so, who owns them? The locals living in the area, the country where these birds can be found, some international organization, one private person?* *4. Can you think about any negative impacts of this scheme on the lives of the local people? What can it be done about it?* *5. Can you think about any negative impacts of this scheme on the local environment?*

the planned follow-up questions for a given task explored by the participants?); (2) Use of the chosen pedagogical strategies (e.g., did the teacher answer these planned follow-up questions himself or did he give space for students to do it?). This would allow me to identify issues and affordances in the design and teaching of the TLPs (e.g., Ian not being able to cover all planned follow-up questions or tasks due to time or behavior constraints) that could impact students' engagement with certain NOS aspects and, consequently, explain data generated by other methods (e.g., absence/presence of certain ideas in diaries and mind maps).

- *NOS questionnaire*: open-ended and containing six questions (available as Supplementary Material accompanying the online article), its completion by students lasted 40 min. The rationale for using open-ended questions was linked to having more diverse insights into what students think about NOS, instead of forcing them to choose between specific (close-ended) options. This would allow a more holistic and flexible coding of their answers (keeping with spirit of the TLPs) and a closer link with findings from other methods. Questions were adapted[6] from two widely employed open-ended instruments from the NOS literature: Driver et al. (1996) and Lederman et al. (2002). Question 1 (Q1) is part of the probes employed by Driver and others (1996) in their study about students' images of science. It was intended to investigate "what students see as characterizing the kinds of questions which scientists address" (Driver et al., 1996, p. 60), being connected with understanding their views about the purposes of scientific work. Similarly, question 5 (Q5) is a more direct question about this topic, also looking at further possible connections students see between science, scientific knowledge and work and the general public. Question 2 (Q2) brings a brief account of Galileo's works to provide some context for discussions involving instrumentation in science, scientific claims and evidence, controversies and certification in science, and sociocultural aspects of scientific research. Likewise, question 3 (Q3), based on Lederman and others' (2002) instrument, is a contextual item that tries to foster students thinking about creative work, use of evidence in science, scientific claims and testimony, competitive theories/explanations, controversies, and certification and bias in science. Lastly, questions 4 (Q4)—based on Driver and others (1996)—and 6 (Q6)—inspired by Lederman and others (2002)—are more closely connected to specific discussions about what scientific theories and models are, how they are usually built and why they are important in science. They are also contextual items and deal both with direct questioning (e.g., "what do you think a 'scientific model' is?") and with more in-depth thinking about science. The use of two different instruments as sources of questions then enabled me to have each NOS aspect from the TLPs (Table 1) linked to at least two of the questions described above (e.g., "controversies in science", explored both in the Medicines and in the Evolution TLPs, is relevant to Q2 and Q3), providing some triangulation among different instrument items. Questions adapted from these instruments were also all context-based and mostly grounded on argumentation, decision-making and topics/cases not explored in the TLPs; this would help me to investigate the transferability of NOS ideas (Khishfe, 2013) explored in the TLPs to other scenarios. Nevertheless, as with any method, this instrument has limitations: some NOS aspects (e.g., "relationships between science, ethics, financial systems, politics") are less apparent in the questions, working against the more holistic view of NOS advocated here. Other methods (diaries, maps and observations) were then important to complement findings from this questionnaire. Its application followed a "pre" and "post" design: before the teaching of any TLP/start of the year ("pre-TLPs") and after the teaching of all TLPs/end of the year ("post-TLPs"), mapping yearlong changes in NOS ideas. Thus, it complements limitations from the other methods: while they can track short-term effects of specific lessons/TLPs, giving nuance to what students are learning, they can be influenced by simple memorization or prior ideas with less insight into long-term effects of the TLPs, as offered by this method.
- *Students' results in their end-of-year exams*: grades from all year 8 groups (anonymised) at their end-of-year exam were collected and compared with the results from the participant group (through *SD* and *t* test). Their purpose was to address my secondary goal in this study: to evaluate possible negative outcomes from this experience to students' learning of the expected content, an empirical step recently advocated in the field (de Berg, 2014).

Data were analyzed qualitatively (Scott, 1996), with the exception of the exam results, looking for patterns and links between findings from different methods and the TLPs. No preconceived categories of "NOS knowledge" (e.g., naïve, advanced) were used and students' ideas were described, trends identified and then interpreted against particularities of the TLPs.

For diaries, entries were thematically organized daily based on the NOS ideas expected to be explored in each lesson (e.g., Tables 2 and 3). For instance, entries from lesson 1 - Medicines were compared with the original TLP and to what actually happened in the lesson on that day (observations). At the end of each TLP, a final analysis was carried out against all NOS aspects planned for that TLP, and trends were identified. Similar approach was adopted for the mind maps: ideas found there were identified and compared against observations and learning goals in each original TLP. Quotations from discussions recorded during the mapping sessions were selected to complement annotations on the maps. NOS ideas not originally planned in the TLPs were also identified in maps and diaries.

Observations (notes and recordings) were analyzed in line with initial findings from diaries and maps, aiming at providing context to how NOS ideas emerging (or absent) from these instruments were liked to Ian's teaching of the TLPs. Specific events when NOS aspects from one TLP were employed by students in a different TLP were also identified to gather insights into the "spiral strategy" chosen to organize and connect the four resources.

For the NOS questionnaire, an inductive coding process generated a total of 33 codes/statements to organize ideas used by students to answer the six questions in that instrument[7] (Coffey & Atkinson, 1996). The choice of organizing their answers in the form of "codes/statements about NOS" was linked to my aim of not categorizing these students into specific epistemological stances (e.g., "naïve") nor their responses as "right/wrong", "adequate/inadequate". That enabled me to generate a more dynamic and holistic picture of their views about NOS, where diverse ideas (even from different philosophical stances) could be simultaneously used when thinking about NOS. This strategy of coding thematically through "statements" (instead of attributing a specific "value" to students' answers) is commonly employed by those in the field who, as done in this investigation, advocate for a more holistic teaching of NOS (as opposed to more declarative approaches), such as Allchin (2011) and Erduran and Dagher (2014), who also have also been arguing for more nuanced and less dichotomic strategies for analyzing data from NOS questionnaires (see also Deng et al., 2011). Table 4 then displays a sample of "codes/statements about NOS" inductively generated from students' answers to the questionnaire, the "description of these codes/statements" and examples of "students' original answers" to illustrate how they link to the final codes/statements.

Statements generated through this coding of students' answers were then transformed into two visual "whole-group epistemic maps" ("pre-TLPs" and "post-TLPs") using "Epistemic Network Analysis" (ENA) (Peters-Burton, 2015). ENA is a visualization method that displays connections (networks) between ideas (codes/statements) within a group (e.g., participant year 8) in the form of an "epistemic map," being helpful to show how distinct ideas about NOS (statements, or "nodes" in ENA language) are used together - i.e., displayed through "connective lines" between these "nodes"/statements. The visualization of students' views about NOS in the form of these networks would then offer me not only a way to organize the statements (and their incidence) in students' answers, but it would also move my analysis beyond the quantification of isolated, standalone NOS ideas/statements, as usually done in this field (Deng et al., 2011; Peters-Burton, 2015). Through this method, views about NOS were then not simply identified and quantified, but connections among them and how they had been linked in

TABLE 4 Sample of the coding system (in the form of statements) applied to students' answers to the NOS questionnaire

#	Code/statement about NOS	Description of code/statement	Example of a student's original answer
Question 1			
6	Science is about facts/right answers	Student's answers that talk about science being interested in finding facts about things and/or fixed/right answers about specific questions and/or proving people wrong.	"It's not scientific because is about choice and not facts."
Question 2			
9	Scientists can resist new or different scientific ideas	Students' answers stating that scientists can resist new and/or opposite/ different ideas/theories, especially if they follow another school of thought.	"Galileo faced a lot of opposition to his theories because people followed Aristotle's ideas and thought that it was true."
Question 3			
10	Instruments and technology impact scientific discoveries/ ideas	Students' answers stating that having access to instruments and other forms of technology can help to develop new discoveries, ideas/theories, or to gather new data/evidence, and so forth	"They disagree because they researched it using different equipment."
Question 4			
12	A theory/model has to be strongly connected to empirical evidence/ experiments to be accepted	Student's answers stating, in different ways, that scientific ideas/theories/ models are based on and have to explain empirical evidence/data/ findings/observations/results from experiments, and so forth	"They came up with their theories by doing experiments."
Question 5			
1	Science involves investigating and expanding knowledge about people and the world	Students' answers related to science being about discovering new things, proving things, finding reasons, learning more about the world, nature, people (babies, for instance), animals, universe, explaining how things work, creating theories, and so forth	"Science helps to know more about who nature works."
Question 6			
10	Instruments and technology impact scientific discoveries/ ideas	Students' answers stating that having access to instruments and other forms of technology can help new discoveries, gathering new data/ evidence, developing new ideas/ theories/models, and so forth	"They can use equipment to develop this model of the earth."

different ways to make sense of scientific work became the most important feature of the findings generated through the NOS questionnaire.

In order to create each epistemic map/network (one pre-TLPs map and one post-TLP map) from students' original answers to the NOS questionnaire, first each student's answer was individually coded using the coding system mentioned above. If an answer to a question encompassed more than one statement, then more than one code was attributed to that answer. For instance, if a student used ideas related to both statements #1 and #6 (see Table 4) to answer her Q1, these two codes/statements were considered as being "connected" among themselves as part of her answer to that question. At a second stage, following the procedure described by Peters-Burton (2015), a 33 × 33 unit matrix was built for each student, with codes/statements from 1 to 33 displayed in both rows and columns. Every time two codes/statements appeared together in the same answer (such as #1 and #6 in the example above), their intersection in the matrix was numbered as 1; all the other cases were numbered as 0, creating a binary ("unit") matrix for each student. For instance, in the case illustrated here, the cell in the intersection of column 1 and row 6 was numbered as 1; similarly, the intersection of column 6 and row 1 was also numbered as 1. Afterwards, all individual "student-matrices" were added together through matrix addition, generating a final "group-matrix" for the whole group. This procedure was carried out for both pre-TLPs answers and post-TLPs answers, generating one pre-TLPs group matrix of answers and one post-TLPs group-matrix of answers.

Lastly, each group-matrix was uploaded to the network analysis software UCINet®, which transformed it into a group network or "epistemic map." The **size of the nodes/statements** (also known as "frequency of use": the larger the node, the more frequently it was used in the answers to the questionnaire), their **location** in the network (close/distant from one another; and peripheral/central to the network: the more central position a statement occupies in the network, the more connections it establishes with other statements), and **network density** (total connections made among statements to answer a question) are relevant data generated by the UCINet® software about these networks that can be used to analyze changes in students' NOS ideas. This analysis was mostly of qualitative nature, mapping differences between pre/post-TLPs networks to examine, at least partially, effects of the experience on their NOS ideas.

5 | RESULTS

Students' ideas about NOS were examined over the school year when the four TLPs were taught, investigating: "In which ways can the teaching of science through the intercultural model of HOS contribute to widening participant students' views of NOS?" I also considered the effects of this experience on their grades to explore if the inclusion of NOS into science lessons would negatively impact content learning. These results will be presented here according to data generation methods used: NOS diaries, group mind maps, observations, questionnaire, and exam results. When suitable, quotations from lessons will be embedded in the presentation of results from other methods to exemplify specific links with the original TLPs.

5.1 | Students' NOS diaries

Students' NOS diaries, written after each lesson of a TLP on "what did you learn today about how science and scientists work?" were useful to track their developing ideas about NOS.

Table 5 displays NOS ideas linked by students to their lessons onthe first three TLPs, revealing that several planned NOS aspects, especially those of social-institutional nature, were identified as ideas they had learnt during those lessons.

For the Medicines TLP, we find mentions to collaborations ("I learnt that people from different countries shared knowledge about illnesses. This helps in science as today scientists can study cures and create new ones"), trials ("It takes long to process the drugs because they have to be tested many times for safety") and natural resources ("I learnt that there are many cures but we do not know what they are due to deforestation") in scientific development. Similarly, in their Magnetism diaries they mentioned links between science, technology and society ("I learnt about the difference between technology and science, and how new technologies can impact the society, like in politics and money"), and collaborations in science ("I learnt that scientists from different places shared ideas and objects that are connected with magnetism"). On the Evolution map, we find mentions to evidence and theories ("Scientists work through evidence and explanation, they are constantly thinking of scientific explanations that will improve their theories"), collaborative work and peer review ("They [scientists] don't always agree. But if they join their ideas they can be more successful").

These diaries can also help to explore which specific activities in a TLP promoted explicit engagement with NOS. In lesson 2 of the Magnetism TLP, for example, they discussed the compass and benefits of being able to travel worldwide on economy, everyday life, science and technology, and politics (task 3, Table 2). Ideas directly explored in this task (e.g., "this could benefit politics because they want to develop trades with other countries"; "people would be getting more materials and trading them"—quotes from lesson 2 observation) are also found in these diaries (e.g., "I learnt about the difference between technology and science, and how new technologies can impact the society, like in politics and money"—quote found in diary from lesson 2). Interestingly, this task 3 is an exemplar case of how the intercultural model of HOS was used in the TLPs, and students' identification of the elements above (and others such as collaborations and exchanges in scientific development) as parts of "how science and scientists work" indicates the potential of this model to exploring NOS aspects not usually found in other resources.

5.2 | Group mind maps

Another relevant method to explore links between TLPs and students' NOS ideas was the group mind map produced in mind mapping sessions, which aimed to promote reflections on what they had learnt from each TLP (see also Kim & Irving, 2010). In these sessions, ideas (content and NOS) about that specific topic were discussed and annotated by students (see Figure 3 for the four resulting maps; NOS aspects highlighted).

In the Medicines map (Figure 3a), different NOS elements can be noticed: financial aspects behind medicines production **("money")**, use of natural resources, and professional **("education, scientists")** and public engagement **("public opinions")**. Looking more closely, we see students' thoughts about how money is related to science (public/private investments and secretive research); how medicines development depends on natural resources and how it can impact nature **("think about animals")**; how it is a **long-term and costly research** and how **testing**, **previous knowledge**, **and exchange of knowledge** are important to this development to ensure safety. These last two aspects, linked to long-term research, testing, and collaborations, are also illustrated by the quote below from this mind mapping session:

TABLE 5 Trends in students' writings in their NOS diaries

TLP	Planned NOS elements (from TLPs[a])	Main trends in students' diaries (NOS elements)	Exemplar quotes from the diaries
Medicines	- Relevance of natural resources to production of scientific knowledge (issues of environmental and intellectual property nature) - Collective nature of the scientific work, exchanges, collaborations and transmission of knowledge - Scientific claims, evidence and testimony in scientific development - Relationships between science, ethics, financial systems, politics, and so forth - Experiment, controlled investigation and quality control in science	- Collaborative and long-term nature of scientific work and knowledge	"Scientists learn from each other to improve their knowledge." (Student E) "I learnt that people from different countries shared knowledge about illnesses. This helps in science as today scientists can study cures and create new ones." (Student K)
		- Knowledge about plants and medicines come from different places around the world	"I learnt that there are many cures but we do not know what they are due to deforestation" (Student L)
		- The importance of testing/trials in science	"It takes long to process the drugs because they have to be tested many times for safety." (Student B)
Magnetism	- Observation and indirect evidence in science - Science is tentative, creative and does not answer all the questions - Social and cultural aspects of science (commercial aims, contextual influences, exchange and transmission of knowledge) - Relationship (and differences) between science and technology - Modeling in science	- Collaborative aspects of scientific development	"I learnt that scientists from different places shared ideas and objects that are connected with magnetism." (Student D)
		- Social and cultural aspects of science - Relationship between science and technology	"I learnt about the difference between technology and science, and how new technologies can impact the society, like in politics and money." (Student K)
Evolution	- Relationships between evidence, explanation and theory in scientific development - Scientific claims, evidence and testimony in scientific development - Collective nature of the scientific work, exchanges, collaborations and transmission of knowledge - Controversies, disagreements and processes of certification (peer review) in science	- Scientific claims, evidence and testimony in scientific development - Relationship between evidence and scientific explanations	"Scientists work through evidence and explanation, they are constantly thinking of scientific explanations that will improve their theories." (Student A)
		- Collaborative and collective nature of the scientific work and processes of certification in science	"They (scientists) do not always agree. But if they join their ideas they can be more successful." (Student J)

(Continues)

TABLE 5 (Continued)

TLP	Planned NOS elements (from TLPs[a])	Main trends in students' diaries (NOS elements)	Exemplar quotes from the diaries
	- Relationships between science, ethics, financial systems, politics, and so forth		

[a]For the sake of comparison, only NOS aspects from lessons when entries were added to the diaries are presented here.

> Researcher: So, you said natural resources. Where do we find them?
> Student I: Globally.
> Student J: Going around the world, like through the Silk Road.
> Student K: From research about these resources.
> Researcher: And how do you do this research?
> Student J: You test them.
> Student I: To see if they work and if there's a danger.
> Student J: It takes time.
> Student I: Yeah, it will depend on the plant, how rare it is, where it comes from.
> Student K: It can take up to many years.

Thus, we can see how specific NOS aspects planned for this TLP (Table 1) are integrated into this map: "Relevance of natural resources to production of scientific knowledge (including issues of environmental and intellectual property nature)"; "Collective nature of the scientific work, exchanges, collaborations and transmission of knowledge"; "Relationships between science, ethics, financial systems, politics, and so forth"; and "Scientific claims, evidence and testimony in scientific development".

The Magnetism map (Figure 3b) also includes NOS aspects: differences between understanding a phenomenon and making use of it ("**many people used before it was explained**"), links between science, technological applications and society (e.g., "**war**," "**trading**," "**migration**," "**politics**"); and the place of indirect observations in science ("**invisible but see the effects**"). When compared with the NOS aspects planned for this TLP (Table 1), quite a few ideas in this map can be correlated: "Social and cultural influences in the production of scientific knowledge" (in the case of links between science, technology and society); "Observation, evidence, and modeling in scientific development" (when thinking about indirect observations of magnetism as a natural phenomenon); and "Relationship (and differences) between Science and Technology" (reflections about knowing how to explain a phenomenon and exploring its applications). Some of these ideas are also illustrated by a conversation in that mind mapping session about the implications of the compass (a technological device) to trading and to knowledge development:

> Researcher: I see here that you have navigation. Why?
> Student L: North pole and south pole.
> Student M: Because the compass can help to guide to where you want to go. For instance, if you want to go a country in the north, then you can follow a compass, like the one from the Chinese made of lodestone.

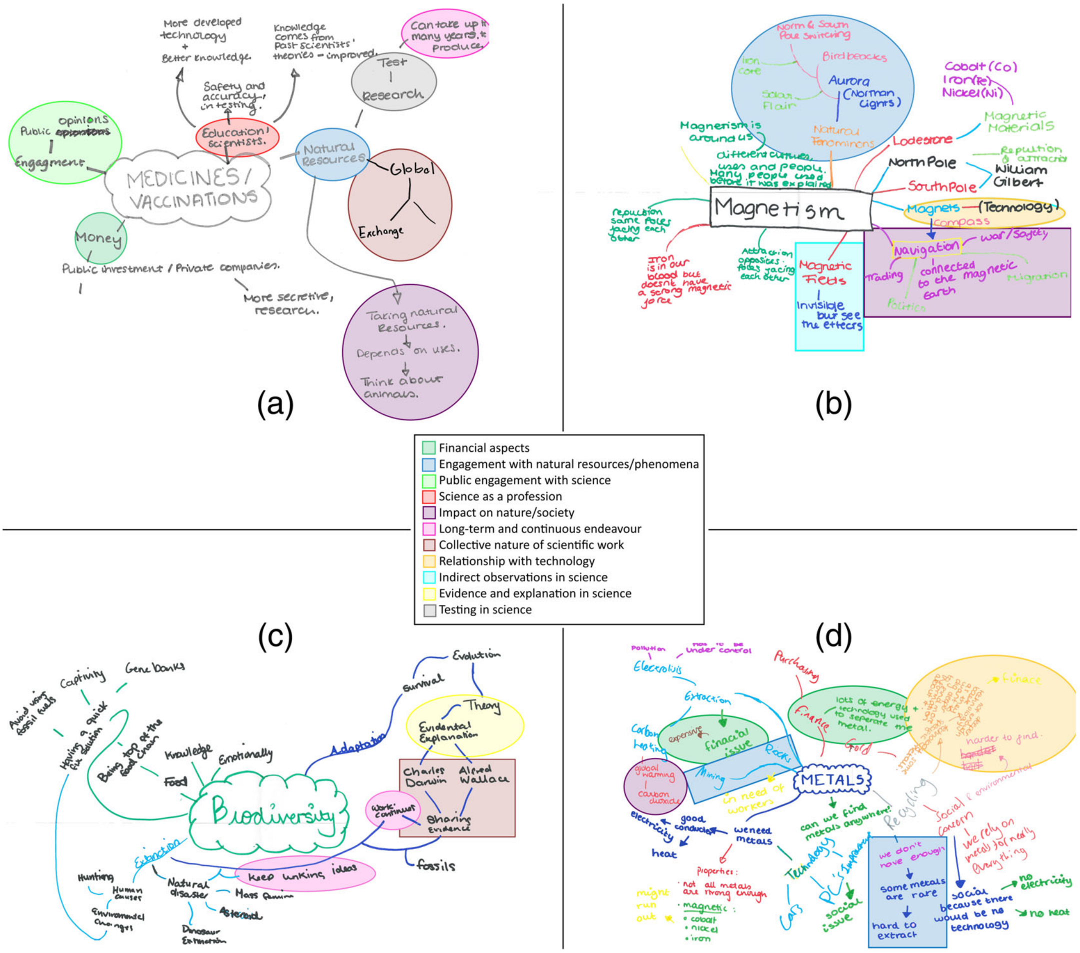

FIGURE 3 Group mind maps after each teaching and learning plans (TLPs)—(a) Medicines; (b) Magnetism; (c) Evolution; (d) Earth's resources [Color figure can be viewed at wileyonlinelibrary.com]

> Student N: The magnetic force of the Earth is strong enough to guide it.
> Researcher: So navigation is connected to the magnetic Earth?
> Student N: Yes, to the magnetic fields.
> Student M: And we can also write down trading here.
> Researcher: Ok, and why are you writing about that?
> Student N: Because that's the history of it, knowing how to use the compass helped people to find their way around, so it's an important development. To say you're in a ship transporting goods, you could use that compass to go around.
> Student L: For knowledge too.
> Researcher: What do you mean?
> Student L: They can travel and advance their knowledge even further.

The Evolution map (Figure 3c) also displays several NOS ideas, mainly linked to theory development and evidence: collective nature of scientific work and processes of certification ("**sharing evidence**"); links between evidence and explanation ("**theory—evidential explanation**"); and continuous nature of the development of scientific theories ("**work—**

continuous"; and "**keep linking ideas**"). In the Earth's resources map (Figure 3d), NOS aspects from this TLP (Table 1) can also be identified: "Relationships between science, ethics, financial systems, politics, and so forth" (e.g., "extraction is **expensive**") and "Relevance of natural resources to production of scientific knowledge (issues of environmental and intellectual property nature)" (e.g., "[recycling because] **we don't have enough, some metals are hard to extract**"; [involves] carbon and heating, [impacts on] **global warming**, "**can we find metals everywhere?**"; "**harder to find**").

When looking at these maps, two main findings can be distinguished. First, and as also seen in the diaries, there seems to be a relevant degree of the integration of some very often under-explored aspects of NOS into students' views about scientific work—for example, collaborations, exchanges of knowledge and resources; relationship between science, technology, environment and scientific development; links between science, politics, finance. These specific NOS aspects are at the forefront of the intercultural model of HOS, and were identified by students in this study as part of what they had learnt about Medicines, Magnetism, Evolution and Earth's resources, illustrating the potential of this approach to widening the scope of NOS learning.

Second, it is also worth noting how these maps include both NOS aspects and the content from the OC (Table 1). This highlights the possibilities from the TLPs (e.g., the use of global, interlinked and holistic narratives about scientific development) to integration of NOS into the OC, especially in the case of topics less traditionally related to NOS such as Magnetism and Earth's resources (Chamizo & Garritz, 2014). Since my main goal was to investigate the potential of the intercultural model of HOS to widening students' ideas about NOS, the fact that these ideas were perceived by them as intrinsically linked to content seems promising to the argument that NOS can be part of school science without negatively competing for space with regular curricula and exams. Even more, it illustrates the benefits of a global perspective of scientific development to the teaching of science not only as a body of knowledge, but also as knowledge production: in global-historical narratives such as the ones used in these TLPs, content and NOS are indissociable.

5.3 | Classroom observations

While helpful to understand the impact of particular TLPs on students' NOS ideas, diaries and maps are TLP-specific (i.e., displaying NOS aspects as linked to particular topics) and, as such, provide less insight into whether NOS ideas developed in one topic (e.g., Medicines) are being employed by students to think about other topics (e.g., Magnetism). To partially address that, I carried out classroom observations to, among other things, understand if the "spiral" strategy adopted in the design of the TLPs was indeed promoting the "return to ideas about NOS in different moments of the school year," as previously explained.

Different authors (Duschl, Maeng, & Sezen, 2011; Forato et al., 2012; Roblin, Schunn, & McKenney, 2018) talk about the importance of long-term, interlinked development of teaching resources, and findings from this study seem to support that. Several cases of overlap of NOS aspects among different TLPs were brought up by the students in the lessons, even when part of different subjects (e.g., Medicines and Magnetism TLPs). The classroom discussion below about the compass, for example, took place in lesson 2 of the Magnetism TLP (Table 2), but exchanges via trading routes (e.g., Silk Road) were first explored in the Medicines TLPs.

Ian: Can anyone remember how this [the compass] got somewhere else?

> Student A: I think that probably the Chinese people would use the compass to go around and then they would meet new people and they would say "what's that strange thing that you have?"
> Ian: Good. So you were not here in the last lesson [when they had started talking about the Chinese compass], so that's a really good answer. So the Chinese would travel to places. What kind of travels are we talking about?
> Student A: Oh, the Silk Route!
> Similarly, in the already mentioned task 3 of the Magnetism TLP (benefits from worldwide travels), I observed another interesting discussion between Ian and a student:
> Ian: Have you got one [impact] for science and technology?
> Student D: For instance, we talked about medicines [TLP], and obviously we don't always have all chemicals that we need to make medicines, so people can travel to other countries and collaborate with other scientists. And obviously if you have more people, you can have more knowledge going into medicine.

Students A's and D's uses of NOS ideas from the Medicines TLP in the Magnetism TLP then display how the spiral strategy resulted in students transferring diverse NOS aspects from previous lessons/TLPs into other contexts. Research that goes beyond the analysis of the impact of one resource on NOS views is scarce (see Khishfe, 2013) and results here hint to the potential of this spiral integration among science topics to long-lasting engagement with NOS.

In addition, it is worth noting how quite a few ideas that students were re-visiting in other TLPs were intrinsically linked to the intercultural model of HOS. Discussions about knowledge and material exchanges—as seen in the examples above where students explicitly linked ideas previously explored in the Medicines TLPs with the Magnetism TLP, and in the exemplar quote from the Earth's resources TLP briefly mentioned in Section 4.3—are key to Global HOS and, consequently, they grounded the narratives employed in all TLPs. Therefore, the fact that students were able to reflect about these NOS aspects in different topics, establishing links among these contexts, shows the potential of using global narratives about science to widen understanding of the complexity, richness and intertwined nature of scientific work.

Lastly, it is also important to highlight here the place of the teacher in the explicit exploration of NOS ideas. Throughout all lessons observed, Ian seemed increasingly comfortable with the proposed question-based and scaffolding-based approaches to the discussions about NOS, despite those being pedagogical approaches relatively new to his practice, and virtually no instances of him having to answer these questions for his students were identified. As specifically explored elsewhere (Gandolfi, 2020), this experience then seems to have provided Ian with opportunities for professional growth around NOS teaching, with his students' active engagement with his lessons and proposed discussions illustrating the value of carefully planned follow-up questions and dialogic work to the explicit exploration of NOS alongside the regular curriculum.

5.4 | NOS questionnaire

To expand the investigation of the effects of the TLPs on students' NOS ideas, a questionnaire was also applied in a pre/post design. Answers were coded through 33 statements and then organized as networks[8] (Figures 4 and 5; summary in Table 6).

Comparison between pre and post-TLPs findings shows an increase in the complexity of students' NOS ideas after the teaching of the TLPs, as measured by the "network density" figures: while both maps contain the same amount of statements (33), the difference in density (18.8 and 22.1% for pre and post-TLPs networks, respectively) shows the rise in connections between ideas about NOS used to answer the questionnaire.[9]

In addition, when compared with results obtained in the prior exploratory study (Gandolfi, 2019b) already mentioned here, where six other groups of students at school A (not taught with these TLPs) responded to the same NOS questionnaire in the previous school year,[10] these results also hint to the effects of the TLPs in widening students' NOS ideas. Students' pre-TLPs density (18.8%) was close to the one obtained by the year 8 group from the exploratory study (17.2%, n = 24), which was also taught by Ian. Nevertheless, their post-TLPs figure (22.1%), obtained at the same point of the school year as for the exploratory year 8 group (i.e., in June, at end of year 8 curriculum, having covered the same content so far), was significantly higher.[11] In fact, students' post-TLPs density was higher than those of all groups in the previous exploratory study (as seen in Gandolfi, 2019b), even than those further ahead in their science studies (i.e., in years 9 and 10). For instance, the best result among older groups (19.8% in one year 9 group, $n = 31$, also taught by Ian) was lower than what the year 8 group taught with the TLPs achieved; while this difference is not very statistically significant,[12] it shows that at the end of their year 8, the group taught by Ian with the TLPs held views about NOS at least as complex and nuanced as their colleagues finishing their year 9 curriculum with the same teacher. While it is important to remember that the six groups from the previous exploratory study and this current participant year 8 were obviously composed by different students (with some having different science teachers as well), students involved in this experience with the TLPs still held more complex and rich ideas about NOS when controlling for the same teacher (Ian) or when compared against older students from higher "ability groups."

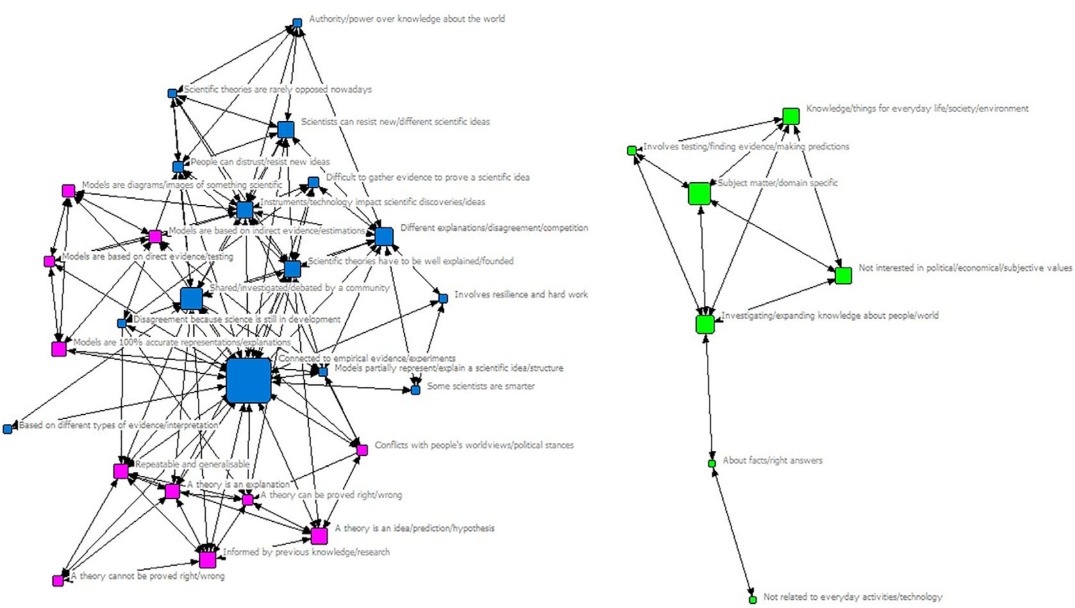

FIGURE 4 ENA of students' answers to the NOS questionnaire (pre-TLPs) ($n = 25$) [Color figure can be viewed at wileyonlinelibrary.com]

The effects of these resources can also be seen in the most frequent and most central statements in the networks: both previous ("Scientific ideas are shared/investigated/debated by a community of people"; "A theory/model has to be strongly connected to empirical evidence/experiments to be accepted") and new ("There can be different explanations, disagreement and competition among scientists"; "Scientific theories have to be well explained/founded") statements acquired more prominence in their thinking about NOS after the TLPs. The number of statements in central positions also increased, implying a more diverse view of which aspects are relevant to describe scientific communities and practices (see table 6).

Another finding is linked to how "utilitarian" statements (Driver et al., 1996) (e.g., "Science develops useful knowledge/things for everyday life, society and environment") became more connected with process-based ideas (e.g., "Scientific ideas are shared/investigated/debated by a community of people") when compared with the pre-TLPs network. This shows the value of the critical work on the use of "utilitarian" examples (e.g., compass, medicinal drugs) done in the TLPs, where these were not explored as illustrations of an idea but under a global perspective about knowledge and technological production.

It is worth noting the change in relevance of the statement "Scientific theories and models can be informed by previous knowledge/research on the topic": while on the periphery of the pre-TLPs network, it had a central place on the "models and theories" cluster in the post-TLPs network, with a high number of links to the clusters "purposes of science" and "production of scientific knowledge." This shows effects of the TLPs on how students view the production

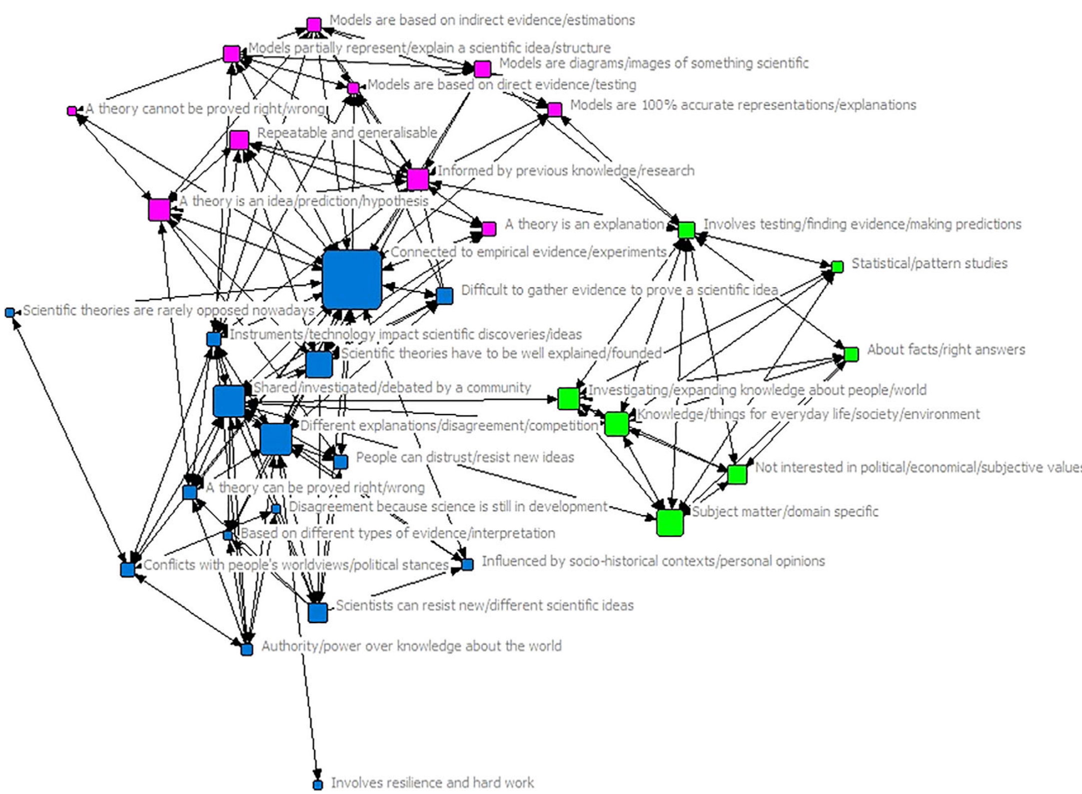

FIGURE 5 ENA of students' answers to the NOS questionnaire (post-TLPs) ($n = 25$) [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 6 Main features of the pre-TLPs and post-TLPs group networks about NOS

Stage	Density of the network (%)	Most frequent statements (largest nodes)	Most central statements (most connected nodes)
Pre-implementation	18.8	• A theory/model has to be strongly connected to empirical evidence/experiments to be accepted • Scientific ideas are shared/investigated/debated by a community of people • Science is a subject matter/domain specific	• A theory/model has to be strongly connected to empirical evidence/experiments to be accepted • Scientific ideas are shared/investigated/debated by a community of people • Instruments and technology impact scientific discoveries/ideas • Science is a subject matter/domain specific
Post-implementation	22.1	• A theory/model has to be strongly connected to empirical evidence/experiments to be accepted • Scientific ideas are shared/investigated/debated by a community of people • There can be different explanations, disagreement and competition among scientists • Scientific theories have to be well explained/founded	• A theory/model has to be strongly connected to empirical evidence/experiments to be accepted • Scientific ideas are shared/investigated/debated by a community of people • Instruments and technology impact scientific discoveries/ideas • Scientific theories have to be well explained/founded • Scientific theories and models can be informed by previous knowledge/research on the topic • Science involves investigating and expanding knowledge about people and the world • Science develops useful knowledge/things for everyday life, society and environment

of scientific ideas, going beyond the sole focus on empirical aspects to include construction of scholarship and collective work. These features are intrinsic to the intercultural model of HOS and this finding points to the development of a more complex and social view of NOS (Driver et al., 1996), now also involving social-institutional aspects that were central to the TLPs.

On the other hand, other statements related to social-institutional ideas (e.g., financial systems and politics) continued to be scarce in the post-TLPs network. These ideas were, however, found in diaries, mind maps, and actively discussed in lessons, hinting to limitations of the instrument in directly addressing some traditionally underexplored NOS aspects, as I will further explore in Section 6.2.

5.5 | Students' results in their end-of-year exam

Different researchers (Clough, 2018; de Berg, 2014) have recently mentioned the importance of exploring if the inclusion of NOS in school science can affect learning of regular content. They are especially concerned with the lack of accounts that also address possible negative effects due to competition for space between NOS and content. Thus, my secondary goal in this study was to consider a potential negative impact of the TLPs on students' content learning by looking at their grades in their end-of-year 8 exam.

Their average grade at the end of their year 8 (38%, $n = 26$) rose by 5% when compared with their average entry grades (33% at their end of year 7 exam, $n = 26$). This group also ranked first (with 3% above the group ranked second) when compared with the average from all other year 8 groups at school A in that year (33%, $n = 178$). Although *SD* for these three figures are too high (18, 14, and 18%, respectively) to yield any significant statistical difference between them,[13] we can at least infer a non-negative impact of this experience on participants' exam performance. This shows the affordances the work explored throughout this article (i.e., integrating NOS aspects and content through overarching and holistic narratives about scientific knowledge and development) to NOS teaching without losing sight of curricular and exam constraints (i.e., the OC).

6 | DISCUSSION

This study aimed at investigating the impact of TLPs grounded on an intercultural model of HOS on students' NOS ideas. In this section, I will reflect on the main findings identified throughout this yearlong experience.

6.1 | Possibilities of the intercultural model of HOS to NOS in school science

As a general finding, the main impact of the TLPs seems to have been on students' understanding of science as a process of knowledge production that involves exchanges, collaborations, long-term work and that is linked to different social aspects. There was an increase in the complexity of their answers to the NOS questionnaire, going beyond a narrow focus on gathering large amounts of evidence ("empirical explanation"—Driver et al., 1996) to establishing a more natural connection between NOS and content - as seen, for instance, in their mind maps.

The adoption of the intercultural model of HOS to inform the narratives in the TLPs also seems to have yielded relevant results in relation to the diversity of NOS aspects explored by Ian and his students. This model was expected to create narratives about scientific work that included a more balanced, interconnected exploration of epistemic and non-epistemic aspects of NOS, a necessary change to current NOS proposals recently advocated by others (Aragón-Méndez et al., 2018; Erduran, 2014; Gandolfi, 2019a; Ideland, 2018). As illustrated by the rise in importance (centrality and citations) of statements related to this dimension in students' post-TLPs network and by the integration of these into their maps, diaries and classroom discussions, this model seems to have promoted a more comprehensive work on the social-institutional dimension of NOS. In addition, this approach also brought traditionally under-explored NOS elements to these science lessons, such as collaborations, exchanges, political and financial aspects. Consequently, it allowed students to engage with instances of knowledge development from a broader perspective, expanding examples of who participates in scientific work, in which conditions and how this knowledge is negotiated and transformed.

The spiral aspect of the TLPs seems to also have impacted students' engagement with NOS in different scenarios. Studies about teaching resources (Duschl et al., 2011; Roblin et al., 2018) have already highlighted the importance of long-term and interlinked units for achieving learning goals, and their effects are clear in this study: the consistency among the TLPs (all informed by a specific historical perspective on scientific development) offered students opportunities to work with similar NOS elements throughout the year. Since experiences of this type specifically linked to NOS teaching are still scarce (Clough, 2018), these findings could potentially be used to inform future development of NOS teaching resources.

Besides this broader work around NOS aspects, the TLPs seem to also have promoted the integration between NOS and content more naturally. As argued by different researchers (Clough, 2006, 2018; Forato et al., 2012), teaching about NOS aspects and content in science lessons can (and should) be done in an interconnected way, such as in these TLPs. With that in mind, data were also gathered to evaluate possible negative effects of the TLPs on students' grades in their final exam, and findings pointed to at least a non-negative impact on their results; thus, bringing NOS to these lessons does not seem to have taken time away from content learning. More importantly, prior to this yearlong experience with the TLPs, this participant group was considered to be the "lowest achiever" in their cohort. This was linked by other science teachers at school A to several behavior issues identified within the group in the previous year and to their grades in their final exam at the end of year 7, the lowest in their cohort. Thus, such a positive result when compared with their starting point further illustrates the potential of a thorough integration between NOS and regular content: it can afford the development of more explicit and engaging classroom discussions about scientists and scientific work without losing sight of the pressures, curricular and exam constraints faced by science teachers.

Therefore, instead of "competing" for time with the expected content, the intercultural model of HOS seems to have promoted a more holistic understanding of scientific knowledge, bringing together its products and processes. As seen throughout this experience, through a careful, coherent, and long-term approach to NOS resources, science lessons can be diversified and enriched through diverse narratives and in-depth discussions and still function within the general expectations from regular curricula.

6.2 | Limitations of the study and TLPs

As with any small-scale project, concerns around scalability of these findings will arise, since the TLPs were implemented in a specific context, with one teacher and one classroom. However, some indicators of scalability, such as sustainability and spread (Roblin et al., 2018), can still be identified here. Following Ian's work with these TLPs in a new school year was not possible due time constraints, but our communication afterwards showed that he was still working with these resources and that his new students were receiving it well (Gandolfi, 2020). While these results are anecdotal at best, they indicate potential for sustainability.

Ian also mentioned to be sharing and advocating these TLPs to other science teachers at school A, a sign of a "spreading process" occurring at the local level (Gandolfi, 2020). This strategy (teacher–teacher sharing) can aid the scaling up of innovative proposals, although sustainable educational change is complex and involves more than sharing new resources (Fullan, 2007). Unfortunately, time constraints rendered it impossible to follow-up this "spreading process" more closely, but Ian's advocacy of these TLPs seems promising.

Limitations of the TLPs can also be identified, such as the "assessment for learning" approach used to explore NOS. There is a high level of skill required for an effective work with dialogic and narrative-based strategies (Leach & Scott, 2002), and in some occasions Ian struggled to cover some questions due to time constraints. In the Magnetism TLP, for instance, discussions about modeling in science were expected (about William Gilbert's and Mary Somerville's works—see Table 2), but they were rushed through by Ian. As a result, two NOS elements planned into this TLP – "Science is tentative, creative and does not answer all the questions" and "The role of modeling in science"—were not properly addressed, explaining, to a certain extent, their absence in this topic's mind map (Figure 3b) and diaries (Table 5).

The fact that some NOS aspects were more explored/favored (e.g., exploration of natural resources, collaborations/exchanges between scientists) than others (e.g., modeling and models in science) in these TLPs can also account, at least partially, for their presence in more or less frequency in the results obtained through the different instruments of data collection. Forato et al. (2012), among others in the field, have already explored this challenge of addressing several NOS ideas at once, advocating more "modest goals" when selecting which ones will be explored in each lesson plan/topic, as we tried to do in this study. And while this can be seen as an obstacle, I contend that this should be taken as an incentive to think more comprehensively about the inclusion of NOS into the science curriculum. That is, if we look at how different topics/content can be linked to a group of NOS ideas in a more holistic manner, not only interconnections between topics can be made, as in this study, but diverse NOS ideas can be spread more widely within the whole curriculum, instead of being "crammed" into only one (or four) topics. Future work with these TLPs and around other topics from the curriculum could then explore alternative ways of balancing a wider variety of NOS ideas throughout the whole curriculum.

In relation to methods of data generation, strategies adopted here also had limitations. As previously mentioned, NOS diaries and group mind maps are TLPs-based instruments and, as such, they work best when paired with other methods (e.g., observations and NOS questionnaire) to explore implications for long-term and transferable engagement with NOS. In addition, each mind map was only produced by one group throughout this study, limiting their insights into whole classroom's data at that point of the data collection. I must also recognize my influence in the production of these group mind maps, since some prompt questions I asked during that work could have led students to include specific aspects on their maps. This is not, however, necessarily negative, since the process of collectively discussing NOS is a relevant and fruitful learning and research opportunity in itself.

Care is also needed when reflecting about the NOS questionnaire, where some statements related to links between science and social-institutional aspects (e.g., financial and political elements) continued to be few in the post-TLPs network. Since these ideas were mentioned in their diaries, mind maps and lessons, we can assume a limitation of the NOS questionnaire in addressing some of these elements more directly, especially those arising from a more intercultural perspective. This reflection links to the importance of using diverse methods to investigate students' NOS ideas and to narrowness of most NOS questionnaires available in the literature, as also argued by Deng et al. (2011).

7 | CONCLUSIONS AND IMPLICATIONS

In this article, I explored the affordances of a particular perspective on HOS scholarship—Global HOS—to school science. More specifically, I was keen to examine the possibilities of a teaching approach based on this scholarship—the "intercultural model of HOS"—to widening how scientific work is portrayed in science lessons. To achieve that, four TLPs informed by this proposed intercultural model of HOS were developed and taught to investigate the following question: "In which ways can the teaching of science through the intercultural model of HOS contribute to widening participant students' views of NOS?"

Among findings arising from the teaching of these TLPs, three can be linked to this question: the place of social-institutional and other often underexplored NOS aspects in NOS learning and students' overall prolific engagement with these elements throughout the TLPs (as seen in diaries, mind maps, classroom observations, and in the increased presence and relevance of such ideas in their post-TLPs network); the importance of teaching NOS through planned tasks and follow-up questions that are interlinked within and among TLPs (the "spiral" approach), creating an overarching and holistic narrative for exploring NOS (as seen in students' mind maps, diaries and classroom discussions); and the impact of such approach on the integration between NOS aspects and regular science content from the curriculum.

As recently argued (Allchin, 2020; Aragón-Méndez et al., 2018; Erduran, 2014; Ideland, 2018), a reconceptualization of NOS, one that embraces the complexity of scientific and technological development (Karisan & Zeidler, 2017), is important if we aim at widening people's views of scientific work and engagement with scientific knowledge when facing deeply complex socio-scientific scenarios of global scale (e.g., climate crisis and COVID-19). But how would that reconceptualization look like? Among possible approaches, a relevant contribution from this study to this question is around the potential of Global HOS scholarship to re-thinking which view of NOS shouldbe brought to science lessons. The "intercultural model of HOS" devised to ground the TLPs facilitated the exploration of cultural-historical diversity in scientific development, leading to the expansion of NOS teaching and learning by re-balancing the work with epistemic and social-institutional aspects and delving into less explored NOS aspects (e.g., political, financial, environmental and intercultural roots of science). Thus, I argue that teaching about NOS can greatly benefit from the engagement with a more complex type of STS scholarship that arises from more holistic, less Eurocentric or purely philosophical approaches, moving away from certain traditions in the field that still focus on very specific and standalone cases of scientific development to inform the inclusion of NOS into school science. As done in this study, NOS teaching should challenge itself by moving towards a more global, diverse and far-reaching understanding of scientific work and hopefully the experience described here can inspire others to embrace this type of reconceptualization of NOS.

The intercultural model of HOS can also contribute to the work of science teachers and educators interested in increasing representativeness and diversity in school science (e.g., Christidou et al., 2016; Ideland, 2018). An intercultural approach to NOS such as the one experienced by the students in this study can offer a pathway to widening their views on what science is and who scientists are, as clearly put forward by some of them: "I think people forget, like, it's not just one person, it's a lot of people in different places working on many ideas"; "Before it was only 'that guy from Europe,' but we never thought about other people working on science, like people from Africa or China". Future research could then further explore the potential of this model in expanding representativeness in science lessons to other curricular and schools' realities, and science teachers interested in this issue could greatly benefit from studies based on more global and intercultural perspectives about scientific work and communities.

Lastly, in a recent review, Clough (2018) argued that more research is needed on the practicalities, especially from science teachers' perspectives, of integration between NOS and content in school science, and I believe the experience described here can offer useful insights and contributions to those interested in including (or increasing) NOS into their regular teaching of science curricula in secondary schools. First, due to its holistic approach to NOS, the intercultural model of HOS provides a platform (an overarching narrative about the development of a scientific topic;a "storyline" strategy) to ground a "dialogue" between NOS and content. As found in the participant students' productions, content and NOS are then not seen as independent from each other, but as intrinsically linked in the narrative built about the topic.

Second, this "platform" offered by the intercultural model of HOS can be expanded beyond one science topic, grounding a whole science course (an "integrated" strategy), as done with the TLPs devised in this study. My argument here is that adopting such long-term and interconnected strategies for teaching different science topics, linking lessons within and among them (a "spiral" approach) is key to promote the "long-term impacts" asked for by Clough (2018), as evidenced by participant students' active connection of different NOS ideas across the curriculum. Linking different lessons and TLPs is vital to promoting long-lasting learning experiences (Roblin et al., 2018), including around NOS teaching, where this type of approach is still scarce (Besson, 2014; Forato et al., 2012). More holistic and interlinked approaches to how scientific development is depicted (e.g., the intercultural model of HOS) can be then helpful to school science experiences that aim both at promoting a better integration of NOS into the curriculum and at potentializing its impacts on widening students' learning of NOS through a long-term and comprehensive approach instead of based on standalone/disconnected topics/resources.

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ENDNOTES

[1] See: www.hipstwiki.wikifoundry.com/page/hipst+developed+cases and www.storybehindthescience.org/

[2] "Narratives" are understood here not as "short stories" or "extracts," as often done in Science Education, but as the products of the work of historians, that is, as historical accounts about different scientific developments.

[3] At the start of the year, all year 8 students at school A are sorted out into three groups according to their performance at their final examination in year 7: "low ability," "average ability," and "high ability." This whole cohort of students is then divided into 9 classrooms according to the following proportion: 25% high ability; 50% average ability; 25% low ability. Thus, all year 8 classrooms at school A, including the one participating in this study, have virtually the same distribution of high, average and low ability students.

[4] Participant students' self-identified cultural background: 46% Asian; 19% Black African; 12% East European; 23% others.

[5] Not carried out for the Earth's resources TLP due to students' need to attend other activities around the school.

[6] This instrument was piloted and then used with other six classrooms (133 students) at school A during the exploratory stage of the larger project. Results from this application can be found in Gandolfi (2019b).

[7] Reliability of this coding system was independently checked by two other educational researchers, resulting in an agreement of 85% between three researchers, with most of issues related to language (i.e., wording).

[8] Clusters: models & theories (pink); purposes of science (green); production of scientific knowledge (blue).

[9] A *t*-test (2-tail) shows significant difference ($\alpha = 0.05$) between these pre and post-TLPs results, with $t(24) = 2.12$.

[10] 133 students from years 8, 9 and 10 (aged 12–15).

[11] A *t*-test (2-tail) shows significant difference ($\alpha = 0.05$) between these two figures, with $t(47) = 2.52$.

[12] A *t* test (2-tail) shows significant difference ($\alpha = 0.30$) between these two figures, with $t(54) = 1.15$.

[13] A t-test (two-tail) shows no difference at several levels of confidence between their average entry grade and leaving grades at the end of year 8, with $t(25) = 0.202$. Similarly, there is no difference between their average grade at the end of year 8 and the average grade from all other year 8 groups in that year, with $t(202) = 0.118$.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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