Exploring and implementing an intercultural model of History of Science to teach about Nature of Science

Haira Emanuela Gandolfi

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Supervised by:
Prof. Shirley Simon
Dr. Ralph Levinson

UCL Institute of Education, University College London, UK

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Declaration:

I, **Haira Emanuela Gandolfi** confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

The inclusion of Nature of Science (NOS) within science education has been advocated for decades and History of Science (HOS) has been employed, among other approaches, to facilitate the integration between learning about the processes of science (NOS) and its products (scientific content). Nonetheless, when investigating current science curricula and school science practices, we identify the use of very few and specific historical cases to teach about NOS, with less attention paid to making a more diversified set of histories available for science teachers and their students.

This scenario and its possible effects on students' views about scientific development were explored in this study through the development of an Exploratory phase at two comprehensive schools in London/U.K., involving five science teachers and their students (aged 12-15), and qualitative methods of data generation (lesson observations, interviews and open-ended questionnaires) and analysis. Findings highlighted students' restricted view about who participates in scientific work (mainly male European scientists and Western communities) and an overreliance on evidence and experimentation as the main features of scientific work, whilst social and institutional aspects were peripheral to their understandings of science. In addition, school science practices that promote (e.g. explicit in-depth discussions, assessment and curricular flexibility) and those that hinder (e.g. implicit, illustrative and stand-alone approaches, focus on content and experimentation in official examinations) knowledge development about NOS and diversity in science were also identified.

In a subsequent phase – Implementation – I investigated possibilities offered by an intercultural model of HOS for the teaching and learning about NOS from a broader and more culturally diverse perspective. Through collaborative work with one science teacher, ideas from the field of Global HOS were employed to integrate discussions about NOS and content in the form of four teaching and learning plans (TLPs) about topics from the year 8 (students aged 12-13) science curriculum in England. This experience, carried out during one school year, was analysed under a qualitative approach with the help of different methods of data generation (e.g. lesson observations, interviews, open-ended questionnaires, group mind maps, etc.).

During this phase, the intercultural model of HOS fostered explicit discussions about NOS and content in a more integrated and dynamic style and the use of different culturally diverse histories of scientific development in the science lessons. This resulted in changes in students' views about scientific communities, with a greater appreciation of the social and institutional dimensions of scientific work and their

connection with epistemic aspects, and a broader understanding of participation and diversity in science. This collaborative work on the TLPs also impacted the participant teacher's professional growth (in-development and in-practice) around the inclusion of NOS in his lessons and the use of whole-class discussions and planned questions as strategies to explore these ideas. In addition, his involvement with these TLPs also positively affected his self-perception as a teacher of subjects outside his specialism and his work on promoting these resources to other science teachers.

Impact statement

The findings from this study have direct impact both inside and outside academia. In the field of Science Education, it provides insights into the development and impact of researcher-practitioner partnerships on educational innovation, curriculum development and teachers' professional, personal and social growth. Of special interest to Science Educators, there are the possibilities offered by the intercultural model of History of Science explored in this investigation to knowledge and practice growth and self-efficacy beliefs of practitioners teaching outside their subject specialism, a relevant finding in the current scenario of shortage of teachers specialised in the STEM subjects in England.

This research also provides useful insights to the field of History of Science into possible pathways for public engagement and dissemination of scholarly historical work about scientific practices and communities. While usually explored in the field of Education, researcher-practitioner partnerships are less common in the domain of History of Science, and my work with a science teacher throughout this investigation can offer some ideas to those interested in more horizontal and collaborative practices of communication of knowledge produced by Historians of Science.

As an educational research, this investigation naturally aimed at impacting educational settings outside academia. I was especially keen to explore contributions from Decolonial and Intercultural discussions that have recently arisen in academic studies about scientific development to practices and science curricula in multicultural settings such as comprehensive schools in England. Throughout this experience, relevant findings for school science (i.e. science teachers and curriculum developers) have been highlighted, and specific teaching and learning plans (TLPs) were also developed, implemented and disseminated to promote innovation around teaching about science and diversity in scientific work.

Beyond the dissemination of these teaching resources, findings and implications from this research were also communicated in the form of different academic articles, published in national, international and professional journals, and as part of oral presentations in several international and national academic conferences.

Dedication

To Bruno, always my compañero, for everything he represents in my life.

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Chapter 1: Introduction

The use of History and Philosophy of Science (HPS) in school science has been advocated by several science educators, historians and philosophers of science (e.g. Collins & Shapin, 1989; Matthews, 1995; Millar & Osborne, 1998; Solbes & Traver, 2003; Höttecke et al., 2012; Allchin, 2014) and explored by different curricular reforms (in England, for example, that was the case for the 1989 National Curriculum for Science, with its attainment target 17 'The nature of science'). According to Matthews (1992), some of the possibilities offered by HPS to the field of Science Education are its impact on: understanding science as an enterprise; students' motivation; and humanisation of science and scientists. Similarly, Höttecke and Silva (2011) summarised its main contributions to school science after their extensive review of the field: promoting conceptual change; learning about nature of science (NOS); and fostering public understanding of science and students' positive attitudes towards it.

Closely linked to this advocacy of HPS for school science is the teaching and learning about NOS. The rationale behind its inclusion in science education is part of a larger reflection about science and scientific communities that was started by studies on History, Philosophy and Sociology of Science (HPSS) in the 1950s and 1960s that aimed to re-think how the production of scientific knowledge is understood by (and portrayed to) the public (Hodson, 2014a; 2014b). The aim was to stop analysing science as only a useful and necessary product to life in modern societies, and to start looking at it as an epistemological and sociological activity involving experimentation, modelling, theorising, collaborations and negotiations, ethical questions, and social relationships at different levels of complexity (Erduran & Dagher, 2014).

The general argument from those proposing NOS as part of school science is that learning about science as a 'process', and not only as a scientific content (the 'products of science'), is necessary for better understanding the complexities behind a field that has been constantly gaining importance and impacting, for better or for worse, the lives of most people around the world (Driver et al., 1996; Erduran & Dagher, 2014). Actively exploring NOS with students then seems to have the potential to promote a more critical, realistic and less idealised view of science, considering both its benefits and limitations (Gasparatou, 2017; Nola, 2017). In this scenario, it is argued that historical and contemporary cases of scientific development can aid the development of lessons that include both learning about science as a process and about its products (i.e. content usually found in science curricula) (Allchin et al., 2014).

This potential of HPS and NOS to bring broader discussions about scientific work to science lessons has been, however, recently questioned by some researchers (e.g. Jegede & Aikenhead, 1999; Krugly-Smolska, 2013; Erduran, 2014; Sarukkai, 2014; Ideland, 2018; Kelly, 2018), especially regarding 'which HPS' is being advocated and employed by the majority of teaching and learning resources available for teachers. According to Sarukkai (2014, p. 1996) the "explicit emphasis on the figures of Western Enlightenment" by HPS does very little to increase complexity in the analysis of scientific development, promoting a very specific image of science and scientific work that can foster a 'biased humanisation' of this community. Sarukkai and other science educators (e.g. Erduran, 2014; Ideland, 2018) have criticised the types of historical narratives that are traditionally used in school science as being very often connected with a specific idea of modern science as solely a Western product of the seventeenth century Enlightenment.

Recent works in the field of Post/Decolonial Science have contributed to this debate by proposing, among other strategies, the analysis of scientific development based on the field of 'Global History of Science' (Roberts, 2009; Elshakry, 2010; Fan, 2012). The main research perspective employed by this field is that modern Western Science (normally understood as a product of the European Enlightenment) is intercultural: a product of exchanges between different cultures and of the circulation of diverse types of knowledge around the world, all promoted by historical and geographical contexts such as trade in the Silk Road and colonising/imperialist projects. Thus, an 'intercultural view' of History of Science (HOS) would involve understanding science as the product of these exchanges, transforming a local historical narrative into a global historical narrative.[1]

School science resources based on this intercultural perspective of HOS when selecting examples and building narratives about science and its nature are, however, scarce in the field, as argued by Erduran (2014) and Ideland (2018). Most discussions about the usefulness of this approach to science lessons are still occurring at a 'theoretical level', with authors highlighting possibilities and strategies, but without actually transforming them into teaching materials and classroom-based experiences.

In this project I will explore whether and how this model can be employed in the development of teaching and learning plans (TLPs) around four different topics from the key stage 3/KS3 (students aged 11-14) National Curriculum for Science in England: Medicines, Magnetism, Evolution and Earth's resources. As a starting point, I believe that this intercultural approach to HOS and NOS can bring a more diverse view of

[1] The term 'intercultural' will be used in this work as often done in the field of Multicultural Education (Pomeroy, 1994), that is, based on the idea of 'interculturality', which refers to exchanges and learnings between different cultures, societies and communities that are negotiated without total assimilation by any side. It differs from the idea of 'multiculturality', which is often understood as the co-existence of different cultures, societies and communities that do not interact with each other.

science to secondary science lessons, tackling the problem of ‘biased humanisation’ while also fostering the learning of NOS in all its epistemological and social-institutional complexities. This would involve exploring, among others, aspects such as collaboration, negotiation and adaptation of scientific knowledge, exploitation of and power-struggles regarding natural resources, ethical, economic and political aspects of science (Erduran, 2014; Ideland, 2018).

In order to investigate the development and implementation of these TLPs, including the integration between NOS and regular KS3 science content, a case study was carried out at one year 8 class (students aged 12-13) in one secondary comprehensive school in London/U.K. through a researcher-practitioner partnership with one science teacher. The participant teacher was then actively engaged in an iterative cycle of development-implementation-assessment of these resources, and audio-recordings of our meetings, lesson observations, semi-structured interviews and informal chats were employed as sources of data for a qualitative and interpretive analysis of this experience.

Throughout this work I will explore affordances and hindrances offered by this intercultural perspective of HOS to school science practices not only by looking at the development of the TLPs as mentioned above, but also by investigating their implementation in regular science lessons from the participant teacher’s and his students’ perspectives. I will argue here that this specific approach to HOS and NOS (informed by debates within the field of Global HOS) can expand the possibilities for NOS teaching while also addressing day-to-day concerns and realities of science teachers in secondary schools, such as high-stake examinations, content teaching, and students’ behaviour and engagement with lessons. In addition, students’ learning from these TLPs (in terms of content and NOS) were also explored through lesson observations, focus groups, diaries about NOS, open-ended questionnaires about NOS and HOS, ground mind maps, and their exam results; all data were mainly analysed using a qualitative-interpretive approach.

In this context of innovative proposals for school science, different studies (Monk & Osborne, 1997; Gooday et al., 2008; Chamizo & Garritz, 2014) have reported a predictable common finding: the great disconnection between the desired goals of a curricular innovation (the ‘intended curriculum’) and what has been effectively taught and learned in the classrooms (the ‘enacted curriculum’). The general reality is that repetitions and standardised problem solving, the “popular, contemporary, cleaned-up, and pre-justified account of the behaviour of the natural world” (Monk & Osborne, 1997, p. 405), are still privileged mainly due to a focus on high-stake examinations and a lack of support for science teachers to put into practice any different proposal or idea (Clough, 2018).

Thus the successful implementation of any educational innovation cannot be achieved simply by imposed curricular proposals, or by top-down development of teaching activities to be distributed to schools. The implementation of new curricular practices, such as teaching about NOS with the intercultural model of HOS, needs to consider the realities and responsibilities of schools and teachers who will be asked to take part in this experience. And this can be accomplished not only by giving them the tools and knowledge to engage with innovative ideas, but also by working actively and collaboratively with them in the construction of these proposals. Therefore, it was not my aim throughout this study to simply present new TLPs to be employed by science teachers, but to actually work collaboratively with the participant teacher, also considering his (and his students') realities and experiences of school science in this process.

In this scenario, the development and implementation of these TLPs was preceded and informed by an initial one-year long exploratory investigation of students and science teachers' uses and engagement with HOS, NOS and diversity in science, and other relevant teaching practices and structural constraints (e.g. curriculum, assessment, timetable). Throughout this initial phase, more than 50 sessions of lesson observations were carried out in two secondary comprehensive schools in London/U.K., involving five teachers and around 200 students enrolled at KS3 and KS4 (key stage 4; students aged 14-16) curriculum cycles, aiming at diversifying the set of school science practices observed to critically inform the development of the TLPs. These lesson observations were followed by interviews with the participant teachers and students about their experiences and impressions of school science and complemented by open-ended questionnaires about HOS and NOS applied to the students to investigate their general knowledge about these topics. The data generated throughout this stage were analysed under a qualitative-interpretive approach, and the main findings and connections between this research phase – 'Exploratory' – and the subsequent development and implementation of the TLPs – the 'Implementation' phase – will be presented and analysed throughout this thesis.

1.1. Context of the study

This study was carried out, as stated above, in the context of comprehensive secondary education in England, focusing on KS3 and KS4 science teaching and learning. At the time of this research (between 2016 and 2018), the participant schools were starting to work with a new national curriculum (DfE, 2014), with first teaching planned for 2016.

The previous national curricula for KS3 (first teaching in 2008) and KS4 (first teaching in 2006) science were both organised around two main ideas: canonical knowledge (scientific content), and ‘key concepts/key processes’ (for KS3) or ‘How Science Works’ (for KS4). The latter strands were closely linked to discussions around teaching about NOS and were an explicit part of these official documents (Turkenburg-van Diepen, 2013). In the case of the KS3 curriculum, the ‘key concepts/key processes’ strand encompassed learning about: “Scientific thinking”; “Applications and implications of science”; “Cultural understanding”; “Collaboration”; “Practical and enquiry skills”; “Critical understanding of evidence”; and “Communication” (Turkenburg-van Diepen, 2013, p. 252-253). In the KS4 document, ‘How Science Works’ involved learning about: “Data, evidence, theories and explanations”; “Practical and enquiry skills”; “Communication skills”; and “Applications and implications of science” (Turkenburg-van Diepen, 2013, p. 251).

In the new national curriculum for science (DfE, 2014, p. 169), while the terms ‘key concepts/key processes’ and ‘How Science Works’ have been dropped, a similar idea named ‘working scientifically’ is still present in the guidelines for KS3 and KS4 cycles. In both frameworks, ‘working scientifically’ is an overarching strand that should be explored in Biology, Chemistry and Physics lessons, and no distinction is made in relation to how teaching this strand would look like for each of these specific scientific areas (contrary to ‘content knowledge’, which is specified for each scientific subject):

> ‘Working scientifically’ specifies the understanding of the nature, processes and methods of science for each year group. It should not be taught as a separate strand. The notes and guidance give examples of how ‘working scientifically’ might be embedded within the content of biology, chemistry and physics, focusing on the key features of scientific enquiry, so that pupils learn to use a variety of approaches to answer relevant scientific questions. These types of scientific enquiry should include: observing over time; pattern seeking; identifying, classifying and grouping; comparative and fair testing (controlled investigations); and researching using secondary sources.

More specifically, ‘working scientifically’ in KS3 should include teaching: “scientific attitudes”; “experimental skills and investigations”; “analysis and evaluation”; and “measurement” (DfE, 2014, p. 201). Meanwhile, in KS4, that should involve: “the development of scientific thinking”; “experimental skills and investigations”; “analysis and evaluation”; and “vocabulary, units, symbols and nomenclature” (DfE, 2014, p. 214-215). According to Reiss (2018, p. 49), however, while NOS is still present in this new national curriculum, “government ministers were suspicious of anything to do” with it, and the question being asked by teachers at the time of this study was how the apparent diminished importance of NOS in these new specifications was going to influence their practice, especially in relation to assessment.

This scenario of uncertainty in relation to the new curriculum was mainly relevant to KS4 teaching in both participant schools, since at end of this cycle students have to take a high-stake national examination known as GCSE (‘General Certificate of Secondary Education’) that would be heavily influenced by this new document. This research was then carried out exactly at the transition period between the start of the teaching of this new KS4 curriculum (2016) and the first round of the new high-stake examinations (2018) that were expected to affect the lessons observed during the Exploratory phase. On the other hand, the KS3 cycle, which was also the context of my Implementation phase, does not involve a national examination, with assessment being mostly carried out internally by the school. Thus, participant teachers at the beginning of this study seemed less concerned about the changes at this curriculum level than at the KS4 context.

In summary, the participant schools, teachers and students were experiencing a relevant period of curricular change during the development of this investigation. While my main research aims were not directly related to understanding the impact of these changes on school science practices, I cannot ignore their presence and possible influence in the participant contexts, and discussions about old and new curricular realities were explored, mainly through interviews, as they appeared in this study.

1.2. Structure of the thesis

Following this introductory first chapter, in chapter 2 I will review the three main topics informing my empirical investigation: Nature of Science and Science Education, History of Science in science teaching and learning, and Intercultural perspectives of HOS to Science Education. In that chapter, I will summarise and analyse the main discussions and ideas developed in the field of Science Education about the possibilities offered by HOS and NOS to the teaching of science from an intercultural perspective.

In chapter 3 I will describe the design proposed for my empirical research at secondary schools in London/U.K., focusing on my research aims and questions, and on the philosophical perspectives, values and ethical aspects involved in this investigation. The chapter ends with an overview of the adopted research strategy, delineating the two research phases (‘Exploratory’ and ‘Implementation’) organised for this study. Chapter 4 will then provide detailed information about the settings and participants involved, along with a description and critical appraisal of the chosen methods and instruments of data generation and analysis (mainly of qualitative nature).

In chapter 5 I will present the main results generated throughout the Exploratory phase divided into three main sections: ‘HOS, NOS and intercultural approaches in school science: a view from the classroom’, which will explore participant teachers’ current practices and views about NOS teaching, uses of HOS, and intercultural perspectives; ‘Different people in different places: students’ knowledge about HOS’, about participant students’ knowledge and views about who participates and contributes to scientific development; ‘Thinking about science: students’ understandings about NOS’, on participant students’ views about NOS. In addition to presenting and exploring the main findings from my Exploratory phase, this chapter will also include an in-depth discussion and reflection about these results, locating and connecting the knowledge generated throughout this research stage with a wider literature on Science Education, NOS teaching and learning, use of HOS in school science, and intercultural and cultural diversity perspectives for Science Education. At the end of this chapter I will also discuss how the findings from this stage informed the planning and development of the subsequent Implementation phase.

In chapters 6 and 7 I will explore the main findings from the Implementation phase, which aimed at developing and implementing four sets of year 8 teaching and learning plans (TLPs) throughout one school year with the help of one participant science teacher recruited from the Exploratory phase. These findings will be presented and analysed in three different levels: the development and the teaching of the TLPs (both to be explored in chapter 6), and the learning through the TLPs from the participant students’ perspective (to be explored in chapter 7). As done in chapter 5, these two chapters will go beyond the presentation of results to also include in-depth discussions about the whole experience of developing, implementing and evaluating the impact of these TLPs on the participant teacher and his students. It will then establish conversations with other research around innovation in NOS teaching and learning, teachers’ engagement with teaching resources development, students’ learning and impressions about NOS, HOS and culturally-diverse science teaching, among other relevant topics from the field of Science Education.

Chapter 8 will offer a final reflection about the findings generated by this study, readdressing the proposed research questions, and analysing the affordances and hindrances of the integration of NOS, HOS and intercultural perspectives into school science. This chapter will also include a reflection about the limitations of this study regarding its methodological design, including sampling, methods of data generation, and scalability. Implications for future research, researcher-teacher collaborations, development of teaching resources and school practices will also be explored.

Chapter 2: Literature Review

Science teaching and learning took a humanistic turn in the latter half of the twentieth century when science educators and curricular reforms started to debate and promote ideas related to 'scientific literacy for all', science, technology and society, and how the scientific community works to develop its practices and knowledge ('nature of science' – NOS). In this scenario, the impact of recent research carried out in the field of History, Philosophy and Sociology of Science (HPSS) cannot be ignored. While the new 'identity' of school science has strong ties with changes in views about what education should be about (mainly due to the rise of constructivism and socio-constructivism), it is also closely connected with recent historical, philosophical and sociological studies about science as a community of practice.

It is my aim throughout this chapter to review some of these connections between the fields of HPSS and Science Education. I will discuss the influence the former has had on school science practices and curriculum reforms, while also reflecting about implications and possibilities of current perspectives arising from the field of HPSS for science education. In section 2.1 I will consider the rise of proposals for teaching and learning about NOS and how they have been taking place in school settings. Section 2.2 will then focus on the affordances and hindrances offered by History of Science (HOS) to the introduction of NOS into school practices. Lastly, in section 2.3 I will present a new approach towards HOS research that has been recently gaining influence in the field of HPSS: 'Global History of Science'. I will explore its differences from current historical approaches to NOS teaching and what this new HOS scholarship can bring to science lessons.

2.1. Nature of Science and Science Education

2.1.1. A general overview

Historically, studies in the field of the Philosophy of Science have been closely implicated in the clarification and reflection about the processes involved in the production of scientific and technological knowledge, often called 'nature of science' (NOS). According to Lederman (2007), the incorporation of philosophical aspects of science into science education has been advocated since the beginning of the twentieth century; in the 1930s, for instance, most of the debates were related to the ‘pupil as a scientist’ approach, where learning about NOS would mean learning how to work as a scientist by following the so-called ‘scientific method’.

In the subsequent decades, science education became attached to views of science and technology “shaped by post-World War II celebration of science and technology and by Cold War politics” (Allchin, 2011, p. 526; Agar, 2012). Policies were adopted by different countries to increase scientific and technological development, often focusing on the production of a specialised workforce for a world where technology was leading most political decisions, as seen during the Cold War and the Space Race (Agar, 2012; Turkenburg-van Diepen, 2013).

In this period, teaching science became an important pathway for producing this specialised workforce, with special attention to ‘teaching how to do’ (also known as ‘process science’). ‘Processes of science’ was interpreted by some projects, such as ‘Warwick Process Science’ and ‘Science in Process’, as teaching scientific inquiry under the scope of an intuitivist and purely process-based method (e.g. ‘how to observe?’, ‘how to interpret?’). These schemes of work usually involved the execution of several fixed experiments that lacked scientific content or context, promoting an image of scientific processes as independent from content, and they received several criticisms at the time (Millar, 1994; Matthews, 1998; Hodson, 2014a).

Several transformations in the field of Science and Technology Studies (STS) during the 1970s and 1980s, such as the increase in the exploration of sociological and psychological aspects involved in scientific work (Erduran & Dagher, 2014; Hodson, 2014a; Ideland, 2018), have consequently impacted this teaching about the processes of science. In this new context of studies about science, approaches towards NOS moved from an idea that theories derive solely from experience and observation (traditional inductivism) to one where theories and observations cannot be disentangled (Chalmers, 2013). The relationship between inquiry process, theory and content thus started to be seen as more intricate than traditional inductivism would usually assume, and educational proposals that focused solely on ‘how to observe’ and ‘how to interpret’ were at odds with that contemporary understanding of how scientific knowledge is produced.

In addition, these new trends in STS also resulted in the acknowledgement of scientific processes as socially constructed and negotiated (Collins & Pinch, 1998; Erduran & Dagher, 2014), being informed by both esoteric (within the scientific community) and exoteric (external to the scientific community) perspectives (Erickson, 2005). Aspects such as the relationship between science and societies (e.g. politics, funding, communication, and ethics) and how scientists work as a social group (e.g. collaborations, competitions, and disagreements) then became relevant when thinking about NOS, including how these social features and contexts of scientific work relate to knowledge production, that is, to its epistemological aspects (e.g. theory construction, observations, data interpretation and experimentation).

These changes in how NOS is conceived within the field of STS can be summarised as moving from views of "science as experimentation to science as explanation and model building" and of "science inquiry as an individualistic process to scientific inquiry as an individual and social process" (Duschl, 2008, p. 276). In the next subsection, I will explore these different views on what 'nature of science' is and their impact on its inclusion in school science.

2.1.2. What is 'nature of science'?

According to Kelly and colleagues (1993), different ways of understanding NOS have been employed historically, most of them usually based on some of the following approaches within the HPSS field: Mertonian norms, Sociology of Scientific Knowledge (SSK), Laboratory Studies, and other socio-cultural perspectives, like feminist studies.

The Mertonian norms (or the 'norms of science') are based on Robert K. Merton's study about scientific work during the period of the European Scientific Revolution in the seventeenth century (Abraham, 1983), and they encompass the following aspects: universalism ("the validity of scientific knowledge is independent of the personal, social, cultural, and national attributes of the scientist and should be evaluated by cognitive criteria"), communism ("the products of scientific endeavours belong to the community of scientists"), disinterestness ("scientists are motivated by a desire to extend the domain of human knowledge, without personal interest in particular scientific conclusions") and organized scepticism ("scientists have both a methodological and institutional mandate to consider only empirically established facts in scientific decision-making") (Kelly et al., 1993, p. 208). This set of norms, however, has been widely criticized by different authors from the SSK and HOS fields for not being the regular account of the scientific world, but for being, in fact, only the 'ideology of science' constructed in the context of the Enlightenment rationality in Europe (Abraham, 1983). That is, these norms do not portray the real and general practices of science ('what science is'), but they build an idealization of what 'science should be' (Kelly et al., 1993).

The rise of psychological and sociological approaches to STS during the 1970s and the 1980s has then led to the development of a scholarship that focused on scientific work as it is and not as it ought to be. The SSK studies, for instance, attempted to break the idealised view of science from the Mertonian norms by arguing for the understanding of the "socially contingent nature of scientific knowledge" (Kelly et al., 1993, p. 209), encompassing aspects such as reliability and replication, and contextual (socio-cultural) influences. These studies are generally represented by the works developed by two closely related groups, the 'Strong Program' and the 'Empirical Relativism' (Kelly et al., 1993).

The 'Strong Program' proposed that the production of 'true' scientific theories should be understood not only from a philosophical perspective, as previously done in the field, but also through sociological lenses. This type of investigation should include the following components: causality (the conditions – psychological, social, and cultural – behind the claims to a certain kind of knowledge); impartiality (examination of successful as well as unsuccessful knowledge claims)[2]; symmetry (how the same types of explanations can be used for successful and unsuccessful knowledge claims alike); and reflexivity (connections with other research in the broader field of Sociology) (Bloor, 1991). Inspired by the Strong Program, 'Empirical Relativism' focused on the reception of new scientific ideas by the scientific community, looking closely at: the question of 'interpretative flexibility' of experimental data (how data can be interpreted differently by different groups); how the local social mechanisms within the scientific community impact closure in the debates around new ideas; and how these local mechanisms of closure are connected to wider social forces (e.g. political contexts) (Collins, 1981).

The SSK, while successful in demonstrating the importance of sociological lenses in the analysis of scientific development, received some criticisms due to its overreliance on sociological concepts (through a 'sociological reductionism') in detriment to other aspects that can also impact this process, such as cognitive and non-human factors (Kelly et al., 1993). Using an ethnographic approach to the investigation of contemporary scientific work, the Laboratory Studies group (or 'Sociologies of Science in the laboratory'), for instance, aimed at understanding science not only as a result of social factors operating within this field, but also as impacted by non-human aspects, such as availability and usage of specific instruments, adoption of measurement scales, and other physical structures. The construction of scientific knowledge should be then seen as informed by scientists' engagement with this 'laboratory world' and all it entails (Latour, 1987).

More recently, other approaches (such as feminist and post/decolonial works) expanded these ideas to a different critical perspective, in which science (and thus, scientific knowledge) is understood as contextual (political, economic, social), being part of a macro-world ('the macro-world of science') that is intrinsically the same macro-world of the society where we live (Ideland, 2018). Therefore, according to these groups, "it is a mistake to assume that science can achieve conclusions independent of

[2] In opposition to a previous tradition of only using sociological lenses to analyse failed theories (the 'Weak Program').

the larger social context in which it works. The social conditions and political commitments of a society deeply influence or shape the questions and claims generated by science” (Kelly et al., 1993, p. 213). Here, science and technology are understood as not simply influenced by decisions made in other spheres of society (e.g. politics), but as inherently part of this decision-making process (as seen, for instance, during the Cold War period, or more recently in the Climate Change debates), a more nuanced and complex view of the relationship between science, technology and society (Erduran, 2014).

In summary, these contemporary views about science and its nature (SSK, Laboratory Studies, and feminist and post/decolonial works) tend to be informed not only by philosophical and historical research, but also by sociological, psychological and ethical aspects involved in the production of scientific knowledge, resulting in more complex ways of thinking about NOS. Inevitably, these different traditions have been generating debates among science educators regarding how NOS should be understood from an educational perspective (Duschl & Grandy, 2013), and research groups have been formed around different approaches.

According to Justi and Erduran (2015) the most cited perspective towards NOS teaching and learning in the literature is the one proposed by the ‘Lederman group’, also known as the ‘consensus view’, which advocates for a distinction between 'nature of science' (NOS) and 'nature of scientific processes' (or scientific inquiry - NOSI). The former is understood by the group as the “values and epistemological assumptions underlying scientific knowledge and its development” (Justi & Erduran, 2015, p. 1), while the latter is formed by “the activities related to the collection and interpretation of data, and the derivation of conclusions” (Lederman et al., 2002, p. 499). Therefore, when talking about science, this group claims to be separating scientific inquiry from its epistemological aspects (Lederman et al., 2014), with NOS including only tenets related to the epistemology of science: tentative; empirically-based; subjective (theory-laden); partially based on human inference, imagination and creativity; socially and culturally embedded; theories vs. laws; observation vs. inference (Abd-El-Khalick & Lederman, 2000; Lederman et al., 2002).

Recently, however, this approach has been receiving criticism from different researchers, who do not agree with the choice of separating scientific inquiry from NOS and with this fixed, rigid list of tenets that seem to be applied to all scientific contexts (McComas, 2008; Erduran & Dagher, 2014; Hodson, 2014a; Martins & Ryder, 2015; Hodson & Wong, 2017; Ideland, 2018). According to Erduran and Dagher (2014), scientific inquiry is a part of NOS and not a separate field, since inquiry is not only a set of methods, but these methods are also connected to epistemic and conceptual ideas in science (for instance, models and theories). Irzik and Nola (2014) also argue that

NOS should encompass both scientific knowledge and inquiry, mainly because science is formed by several characteristics that are not discrete entities, being thus connected and interrelated, making it very difficult to separate values, epistemological assumptions and sociological aspects from the scientific inquiry itself, as also claimed by contemporary HPSS research (e.g. Collins, 1981; Latour, 1987).

The nature of scientific work should then be seen as the result of interactions between different aspects, and it should not be rigidly divided into unrelated areas (such as 'nature of scientific knowledge and its development' and 'nature of scientific inquiry'). This interconnected view of nature of science seems interesting from an educational perspective, since it is hard to conceive teaching about NOS as something distinct from its inquiry features. In this scenario, this detachment would more likely bring odd types of activities to school science where inquiry and 'the other aspects of scientific work' do not influence each other.

Other criticisms to the Lederman's group approach are related to their list of seven NOS tenets mentioned above: it is considered too narrow and rigid, and also to be portraying a homogeneous view of science, features that make the implementation of this list in actual science lessons difficult unless if working with these tenets in isolation (Allchin et al., 2014). Irzik and Nola (2011) summarize these criticisms by saying that this list is too monolithic, with NOS seeming to be fixed, decontextualised and time-independent. This approach then assumes the existence of a specific and unique nature of science – 'the' nature of science – that applies to all different scientific practices and communities (e.g. Biology, Physics and Chemistry), ignoring variability and dynamic aspects involved in carrying out scientific work. In this study I position myself in agreement with this criticism, opting to use the term 'nature of science' instead of 'the nature of science' to highlight my view of scientific practices and communities as diverse and ever-changing.

Differing from the 'Lederman group', Hodson (2014b, p. 912) understands NOS as a sum of scientific inquiry and scientific knowledge characteristics, enclosing, among others: the role and status of the scientific knowledge that scientific inquiry generates; the modelling that attends the construction of scientific theories; the social and intellectual circumstances of their development; how scientists work as a social group; and the ways in which science impacts and is impacted by the social context where it is located. Similarly, Irzik and Nola (2014) base their perspective on the idea that NOS is a group of shared characteristics between different types of science[3] that

[3] Trying to overcome the issues raised by increasingly complex and varied contemporary sciences, the authors called this view of NOS as 'Family Resemblance Approach' (FRA), which is based on Wittgenstein's works and is essentially a dynamic and interactive take on science, opposed to a discrete set features of NOS (Erduran & Dagher, 2014).

operate in different levels (e.g. micro- and macro-worlds), such as postulations, experimental exploration and measurement, modelling, ordering system, predictions and explanations, creativity, and cultural values (Erduran & Dagher, 2014).

Driver and colleagues (1996) argue about the importance of understanding the interrelations between the purposes of science, the nature of its knowledge (epistemic dimension), and its status as a social institution (social dimension), opting to divide NOS aspects relevant to science education into three main groups, based on some common and interconnected core ideas: purposes of scientific knowledge, nature of scientific knowledge (observations, experiments, explanations – theories and warrants), and science as a social enterprise. Likewise, Erduran and Dagher (2014), Martins and Ryder (2015), and Aragón-Méndez, Acevedo-Díaz and García-Carmona (2018) highlight that teaching about NOS should encompass a dynamic approach towards the relationship between epistemic and non-epistemic (or social-institutional) aspects of scientific work.

The influence of some of the socio-cultural perspectives previously mentioned here appears clearly in these different approaches to NOS, which are based on historical, sociological and philosophical contributions to the identification of elements of NOS. Furthermore, these proposals are not rigid lists of tenets, since they seem to bring wider and more dynamically interconnected ideas and reflections to these debates, avoiding being too narrow or too specific (which could be a problem when working with different scientific subjects – Chemistry, Physics, Geology, Biology).

In general, these holistic/interconnected and dynamic perspectives about NOS, also advocated by other science educators (McComas, 2008; Allchin, 2011; Matthews, 2012), seem to offer a promising pathway for its incorporation into school science. A more interconnected view about NOS can ease its integration with scientific content, with both seen as part of a wider process of knowledge development (Taber, 2008; Martins & Ryder, 2015; Billingsley et al., 2016). Throughout this investigation, these possibilities will be further explored.

After briefly examining these debates about what NOS is (summarised by table 1 below), what is the real benefit of its inclusion into school science? If disagreements about NOS are still persistent within the field, why bring it to already overloaded lessons? Are all these discussions useful for science education? If not, which ones could find their ways into lessons to aid science teachers in their practices?

Table 1. Brief outline of the main views about NOS found in the field of Science Education

View on NOS	Main characteristics	Strengths	Weaknesses	Main references
Consensus view	• Separation between NOS ('epistemology of science') and NOSI ('inquiry'); • List of 7 NOS tenets (tentative; empirically-based; theory-laden; partially based on human inference, imagination and creativity; socially and culturally embedded; theories vs. laws; observation vs. inference).	• Systematic and clear organisation of NOS aspects to be explored in school science; • Development of several sets of activities and extensively validated instruments to assess knowledge about NOS.	• Rigid list of NOS aspects that do not necessarily apply to scientific contexts and are not open to change over time; • Dissociation between epistemological and inquiry aspects of scientific work.	• Lederman et al., 2002. • Lederman et al., 2014.
Family Resemblance Approach (FRA)	• Shared characteristics between different types of science that operate in different levels (epistemic and social-institutional) and scales; • Consideration of the different types of scientific disciplines and their mutability.	• Balance between epistemic and social-institutional aspects of NOS; • Holistic view of scientific work; • Dynamic approach to how different types of science can change and interact over time.	• Great complexity in the analysis of scientific work that might pose difficulties for teachers to integrate NOS into regular lessons; • Empirical experiences focus on older students (upper secondary and university levels).	• Irzik and Nola, 2014. • Erduran and Dagher, 2014.
Interconnected/ holistic views	• Connection between epistemological and inquiry aspects; • Focus on both philosophical and sociological aspects; • Exploration of the interrelationships between science and society.	• Balance between epistemic and social-institutional aspects of NOS; • Holistic view of scientific work.	• Lack of empirical proposals available; • Not much discussion on forms of assessment and integration into school science.	• Driver et al., 1996. • Matthews, 2012 ('Features of Science'). • Allchin, 2012a ('Whole Science'). • Hodson, 2014a; 2014b.

2.1.3. Why teach nature of science?

The inclusion of NOS in regular science lessons is commensurate with goals of contemporary science education, such as 'scientific literacy for all' and 'science, technology, society and environment' movements (Hodson, 1992; Lederman, 2007; Aragón-Méndez, Acevedo-Díaz & García-Carmona, 2018). Despite the different views on what NOS is, as discussed in the previous section, there seems to be a widespread agreement about the need for its incorporation into science education. Different authors emphasize the importance of NOS so students can appreciate science as an enterprise and as a process of knowledge production about the natural world with its own strengths and limitations (e.g. Driver et al., 1996; Abd-El-Khalick & Lederman, 2000; Allchin, 2011; Ideland, 2018).

According to Driver and others (1996) and Forato and others (2012), this understanding of science as more than its products is relevant to people living alongside the products of science and technology in modern societies, since it can generate a more realistic and less idealised view of its benefits and limitations and hindrances. Furthermore, contemporary concerns about anti-science feelings and the spread of 'alternative facts'[4] (think, for instance, about anti-vaccination movements, Global Warming deniers and 'Flat-Earthers'[5]) can be partially connected to a lack of understanding about what science is and how it works (Gasparatou, 2017; Nola, 2017). Gasparatou (2017, p. 7) argues then that learning about NOS can help to overcome some of these anti-science feelings while also avoiding the other extreme of blind scientism and idealisation of science:

> (...) students should get the whole story, e.g. about how the structure of the DNA was put together, how competitive the whole process was, how many years it took, how many people were involved with their own ambitions, expectations, insecurities, etc.

It is also worth discussing that teaching about NOS can have different purposes in different contexts (Driver et al., 1996; Matthews, 1998; Jiménez-Aleixandre, 2015). There are, thus, distinct arguments about the importance of NOS to the field of Science Education, such as: utilitarian (e.g. to learn to manage and produce technological objects), democratic (e.g. to engage with the debates about socio-scientific issues),

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[4] 'Alternative facts' are related to opposing official and/or scientific data with alternative/different information/interpretation, being connected to the now known as 'post-truth' era, where "objective facts are less influential in shaping public opinion than appeals to emotion and personal belief." (Post-truth, n.d.)

[5] See here: https://www.theguardian.com/global/2018/may/27/is-the-earth-pancake-flat-among-the-flat-earthers-conspiracy-theories-fake-news

cultural (e.g. to appreciate science as a major part of modern world), moral (e.g. to acknowledge the existence of a scientific community making decisions about science) and learning (e.g. to support teaching strategies, like debates and collaborative work) (Driver et al., 1996; Millar, 1996).

Ryder (2001) and Allchin (2014), for instance, propose 'functional' NOS, arguing that the importance of NOS relies on the possibility of bringing practical issues about science and its relations with society to school, features that could enable students to engage with socio-scientific issues. In this scenario, the relevance of NOS to science education would be mainly related to the acquisition of competence ('understanding' and 'discerning' skills) in science to not only work with conceptual knowledge, but also to understand how science generates this knowledge and how it is connected with the lives of people in different contexts (Matthews, 1998; Allchin, 2012a; Schwartz et al., 2012).

In this study, these different perspectives were considered, and the position assumed was that NOS activities and discussions promoted in science lessons should be related to functional, moral, cultural, democratic and learning rationales (Driver et al., 1996; Millar, 1996; Ryder, 2001; Allchin, 2014; Ideland, 2018). In addition, I also assumed that the introduction of NOS into school science could not only benefit students, but also their teachers, since this approach has the potential to generate more contextualised and interdisciplinary teaching strategies, while also helping to build a cohesive narrative about the development of the regular content being taught. It will be then argued throughout this work that discussions about NOS can provide teachers with powerful pedagogical tools to engage and stimulate their students to critically think and talk about the topics they are learning in their science lessons.

If we then understand some of the possibilities of NOS for school science, what would be the best approach to be adopted in its teaching?

2.1.4. How to teach nature of science?

In recent decades, those who advocate the inclusion of NOS into regular science lessons started to reflect upon and investigate the different scenarios, possibilities and activities that could foster the transposition of these theoretical debates to everyday school science. Regarding the work with aspects of NOS in primary and secondary schools, science educators have been dedicating their research to try and answer the question 'how to teach nature of science?', and some ideas have been proposed.

According to Driver and others (1996), for instance, the process of learning NOS should include, from the more holistic viewpoint discussed before: the collection, manipulation and description of scientific data; the making of generalizations; the testing and comparison of theories; the analysis of applications of scientific knowledge in specific contexts; the understanding of the influence of different factors in a natural system; the evaluation of disputes in science and of socio-scientific issues; and the understanding of scientific revolutions from the HOS. In turn, other researchers (e.g. Matthews, 1998; Forato et al., 2015) argue for ‘modest goals’ when teaching NOS, since the work with only some aspects at each time seems to produce deeper and better results in students' learning than activities involving several NOS aspects simultaneously.

The choice between the different frameworks of NOS discussed in section 2.1.3 (see table 1) and of how many and which of these aspects should be explored in a science lesson does not, however, solve some concerns teachers might have about ‘how to’ include NOS in their regular practices. Obviously, there is not only one way of taking NOS to school science, but some empirical investigations appear to be generating relevant ideas for science teachers and educators.

One of the main debates in this field is related to teaching NOS implicitly or explicitly. The first approach involves working with aspects of NOS that are part of a regular lesson without being specifically addressed and discussed by the teacher with their students; that is, NOS learning is understood as a by-product of a more general activity and not as a planned outcome (Fouad et al., 2015). The explicit perspective, on the other hand, aims at exploring NOS clearly in class, promoting reflections about them as they appear (McComas, 2008).

These two approaches have been extensively investigated and a consensus seems to have been achieved on the more beneficial impact of the explicit perspective (Allchin, 2012a). According to Hodson (2014a), research has shown that it is important to deal with the teaching of NOS objectively and explicitly during a class since students will not necessarily comprehend these meta-scientific aspects of science by only getting in contact with them without careful reflection. Driver and others (1996) state that science lessons can convey implicit messages about NOS to students, even when it is not the teacher’s main purpose; hence, they question the impact of the implicit approach on distorting students' views about science, since these ideas are not always actively debated by them and their teachers.

Similarly, Deng and others (2011), while reviewing empirical works involving NOS teaching and learning, concluded that explicit approaches offer better results in school interventions designed to impact students' views about NOS than implicit ones. Thus, science educators tend to agree with the argument for the “rejection of the belief that students will develop good NOS understanding as a by-product of engaging in other learning activities - for example, those relating to acquisition and development of basic scientific concepts” (Hodson, 2014a, p. 2).

Another discussion in the field is related to the use of contextualised or decontextualised activities (Clough, 2018). The decontextualised approach is generally seen in instances where NOS aspects are addressed by ‘add-on’ tasks explored independently of any scientific content or context of scientific work, like reflecting about a ‘magic cube’, puzzle-solving, ‘black-box’, pictorial gestalt switches, and others[6]. According to Clough (2006, p. 472) these NOS activities are “isolated or tangent from science content and scientists”[7] and their “primary purpose is to directly illustrate important ideas about the NOS” independently from scientific content, especially those related to epistemic and inquiry aspects (e.g. observations, inferences).

A contextualised perspective is related to the study of some aspects of NOS in connection with specific scientific content and within a specific setting (such as historical or contemporary examples from scientific practice), enabling students “to make connections with aspects of NOS in the context of the activities they are engaged in”[8] (Fouad et al., 2015, p. 1107). Several authors, especially those speaking from an opposite viewpoint to the fixed list of NOS tenets discussed before (Driver et al., 1996; Allchin, 2014; Erduran & Dagher, 2014; Clough, 2018), argue that NOS is historically and sociologically context-based, thus it needs to be addressed in science lessons with respect to these scenarios.

Aragón and colleagues (2018), for instance, proposed the use of the historical case of Semmelweis’s work on cross-contamination in the context of his research on childbed fever to inform discussions about epistemic and non-epistemic aspects of NOS with prospective Biology teachers. Here, rather than opting for a decontextualised approach, the use of ‘contextualised cases’ such as Semmelweis’s work goes beyond the traditional NOS (e.g. theories, explanations, falsification) to more ‘in-the-making’

[6] For more examples see: http://msed.iit.edu/projectican/.

[7] This decontextualised approach shares some similarities to what Gilbert (2006, p. 967) calls ‘model 1’ of use of contexts in Chemistry Education, which “focuses on the abstract learning of a specific language without framing the setting and the behavioural environment in advance”. This model of context cannot in fact be classified as a ‘contextualised approach’, since it: “does not introduce students to the social, spatial, and temporal framework of a community of practice; does not provide a high-quality learning task because the behavioural environment is sketchy almost to the point of invisibility; does not provide a vehicle for students to acquire the coherent use of specific language; and invokes very little background knowledge in any significant manner” (Gilbert, 2006, p. 967).

[8] This contextualised approach is similar to Gilbert’s models 3 (“Context as provided by personal mental activity”) and 4 (“Context as the social circumstances”). While model 3 understands ‘context’ as connected with the construction of a narrative about a situation that is relevant to the topic being discussed in the lesson, model 4 further develops this idea by also considering this context as informed by social aspects surrounding the situation under analysis.

NOS (Allchin, 2014). Thus, a contextualised approach appears to offer not only the possibility of improving knowledge about epistemic aspects of NOS, but it can also lead to a more critical and global understanding of how science works, including its social-institutional dimension and relationships with other fields.

While we cannot ignore that context-based approaches can pose some difficulties to teachers and students when trying to transpose the ideas being explored to other contexts, an explicit and reflective work might help them to overcome these barriers and realise underlying connections in how scientific development is carried out in different situations. In this project, this approach was adopted in the Implementation phase: the TLPs were all context-based, but an effort was made to explicitly look for connections between different NOS aspects being explored by different examples, lessons and topics.

Additionally, authors (Galili & Hazan, 2001; Leach et al., 2003; Clough, 2006; 2018; McComas, 2008; Toplis, 2011; Allchin, 2012a; Develaki, 2012; Forato et al., 2012) also argue that through the contextualised approach connections between content and NOS can be made more easily by teachers. According to Clough (2006) and Toplis (2011), teaching about the products of science (content) and its processes (NOS) is not dichotomic, since they are two parts of the same scientific enterprise, being both addressed by the use of a context: “NOS issues [are] entangled in science content and its development” (Clough, 2006, p. 474).

As also stated by Leach and others (2003), Taber (2008) and Clough (2018), this perspective of including NOS alongside the regular science curriculum is likely to facilitate teachers' work by managing to explore what is expected by the schemes of work and assessment instruments while also developing innovative pedagogical strategies. In this scenario, there is a growing agreement among science educators that an integration between NOS and content can be more easily explored by teachers working under the influence of an official science curriculum through the use of contextualised approaches. Kim and Irving (2010), for instance, present the positive impact on learning of content and NOS promoted by their unit on genetics (secondary level Biology) informed by a historical approach. According to the authors, their context-based approach enabled the teacher to address explicitly both the scientific knowledge and some relevant meta-scientific aspects related to this topic. In her unit about gravitation for secondary Physics, Develaki (2012) also emphasizes the importance of this contextual and non-dichotomic approach to content and NOS to avoid well-known problems with time constraints and exams.

In summary, while NOS can be introduced into science lessons in different ways, the present study aligns itself with those advocating holistic, explicit and contextualised approaches that also promote the integration between NOS and regular content teaching. In this scenario, Allchin (2014) argues that there are at least three ways of developing these explicit, contextualised and integrated NOS teaching strategies: ‘Inquiry activities’ (engagement with cases of scientific research, including hands-on activities), ‘Contemporary cases’ (study and reflection about an actual scientific topic, such as those often connected with socio-scientific issues) and ‘Historical cases’ (learning NOS through HOS).

In the inquiry-based approach, students engage with scientific research (based on actual research, their own interests, or other ideas proposed by the teacher), carrying out some inquiry activities, such as designing the methodology, analysing and isolating variables, collecting data (mainly through experiments and/or observations), and also developing technical and analytical scientific skills. This type of project can address several NOS aspects, especially those linked to evidence, claims, theories, and inferences. Allchin and others (2014), however, state that if not informed by SSK and Laboratory Studies, this approach can enclose problems with the idealization of scientific methods, failing to include cultural perspectives, social debates and contingency[9], such as the ‘process science’ projects from the 1970s.

In order to avoid some of these limitations of the inquiry-based strategy, contemporary cases can enable students to engage with critical thinking, since this approach is related to the study, debate and reflection about contemporary scientific topics often connected with socio-scientific issues and that are on the frontiers of science (Tala & Vesterinen, 2015). In this scenario, the role of data analysis, expertise, testimony and communication in science is widely addressed by the cases and the importance of cultural, political and social aspects of science can (and should) be explicitly reflected by teachers and students to foster the learning about the chosen case (Allchin et al., 2014).

Nevertheless, employing contemporary cases could also find some obstacles inside the classroom, especially because, as they are contemporary, these cases do not necessarily have an actual result or ‘right answer’, such as the debates around Global Warming. Thus, they cannot always provide all the information needed to the debate or the closure generally expected from science lessons, at least from students’ and official exams’ perspectives (Allchin et al., 2014). While not necessarily problematic, these characteristics of contemporary cases discussed by Allchin and colleagues (2014) can become an issue for science teachers who do not feel comfortable working in these specific scenarios of uncertainty.

Historical cases, which were once contemporary, can offer the broader perspective of contemporary cases alongside a certain degree of closure provided by

[9] Some exceptions to this scenario can be found in projects connecting inquiry with, for instance, socio-scientific issues (SSIs), such as: PARRISE (Kyza & Levinson, 2014) and STEPWISE (Bencze, 2017).

history, being a promising way of bringing accounts of scientific research to the science curriculum. According to Allchin and others (2014), using historical cases to teach NOS can enable students to learn about changes of ideas and concepts, tentativeness and errors in science, prediction, methodological pluralism, socio-cultural contexts (collaborations, bias, funding, controversies, criticism, and communication), among others. In the next section, special attention will be dedicated to the teaching about NOS through these historical cases, a strategy that will also inform the empirical phases of this investigation.

2.2. History of Science in science teaching and learning[10]

2.2.1. A general overview

The inclusion of HOS in school science has been recently advocated by several science educators and historians (e.g. Collins & Shapin, 1989; Matthews, 1995; Millar & Osborne, 1998; Solbes & Traver, 2003; Höttecke et al., 2012; Allchin, 2014; Garcia-Martinez & Izquierdo-Aymerich, 2014), and explored by different academic journals (e.g. 'Science & Education' and 'Journal of Research in Science Teaching'), conferences (e.g. organised by the 'International History, Philosophy and Science Teaching Group', and by the 'European Science Education Research Association') and curricular reforms around the world.

Suggestions of the association between HOS and Science Education first began to gain traction in the post-World War II period, aiming at understanding the relations established between science, technology and society (Figueirôa, 2009). One of the landmarks of this movement was a proposal deployed by James Conant and other professors of Harvard University in the 1950s, known as the 'Harvard Case Histories in Experimental Science', in which students were encouraged to study historical cases based on the analysis of key processes in the development of science (Collins & Shapin, 1989).

In the following decades, different contributions were developed to bring HOS into the teaching and learning of science. Matthews (1992), for instance, discusses some relevant local initiatives, such as the report written in 1963 by the British Association for the Advancement of Science (BAAS) advocating teacher training in History and Philosophy of Science, and a conference on HOS and Science Teaching organized in 1987 by the British Society for the History of Science (BSHS). In the

[10] This section was previously published as part of a paper analysing some results from the empirical investigation to be further explored in this thesis (Gandolfi, 2018a).

curricular field, some countries also acted innovatively in relation to HOS, such as the first National Curriculum (from 1989) in England (Taylor & Hunt, 2014), which argued that:

> Pupils should develop their knowledge and understanding of the ways in which scientific ideas change through time and how the nature of these ideas and the uses to which they are put are affected by the social, moral, spiritual and cultural contexts in which they are developed. (NCC, 1988, p. 113).

New attempts to introduce HOS into school science appeared in revisions of the English National Curriculum over the 1990s and the 2000s in the form of guidelines[11], being usually linked to teaching about NOS. To illustrate that, the most recent curricular revision launched in England in 2014 states that:

> Teachers should feel free to choose examples that serve a variety of purposes, from showing how scientific ideas have developed historically to reflecting modern developments in science and informing students of the role of science in understanding the causes of and solutions to some of the challenges facing society. (DfE, 2014, p. 4).

Ideas from these debates, reports and curricular innovations, however, do not seem to have been largely included in science lessons. Almost twenty years ago, Monk and Osborne (1997) suggested that, after the 1989 National Curriculum, several projects were developed, but few were successful in incorporating HOS into science teaching, mainly due to the overwhelming concern about the products of science rather than its contexts and processes. Some recent reviews (e.g. Clough, 2018) tend to agree that this behaviour is still present in school science, although researchers also highlight positive experiences using HOS in lower and upper levels of education (e.g. Höttecke & Silva, 2011; Guerra et al., 2013; Besson, 2014; de Berg, 2014a; Levrini, 2014; Henke & Höttecke, 2015). The already discussed interest in bringing NOS to school science seems to be promoting a slow but progressive introduction of innovative approaches into science lessons and HOS has been receiving more attention in this scenario.

[11] Although mainly disconnected from the official assessments.

2.2.2. Why HOS?

In this context of increasing interest in HOS in the field of Science Education, it is important to reflect about how it can contribute to distinct goals of science teaching and learning. The different roles this approach can play in learning environments have been presented and systematized by several authors in recent decades (e.g. Collins & Shapin, 1989; Millar & Osborne, 1998; Slezak, 1999; Solbes & Traver, 2003; Stinner et al., 2003; Höttecke et al., 2012; Alvarez-Lire et al., 2013; Bächtold & Guedj, 2014; de Berg, 2014a; Garcia-Martinez & Izquierdo-Aymerich, 2014; Aragón-Méndez, Acevedo-Díaz & García-Carmona, 2018), and a compilation of some possibilities was produced by Matthews in 1992 (p. 17-18):

> (1) it motivates and engages pupils; (2) it humanises the subject matter; (3) it promotes the better comprehension of scientific concepts by tracing their development and refinement; (4) there is intrinsic worth in understanding certain pivotal episodes in the history of science - the Scientific Revolution, Darwinism etc.; (5) it demonstrates that science is mutable and changeable, and that consequently current scientific understanding is liable to be transformed, which (6) thus combats scientistic ideology; and finally, (7) history allows a richer understanding of scientific method and displays the patterns of change in accepted methodology.

Based on this list, HOS seems to be related to three main aspects of science education: learning a scientific concept, learning about science as process and its nature (NOS), and fostering students' positive attitudes towards science (Höttecke & Silva, 2011). HOS can be then employed in school science in different manners, based on the goals of a specific science teacher and/or science curriculum. It can aid the learning of scientific concepts by illustrating how they were historically developed by the scientific community, including the analysis of historical data, instruments and experiments (as seen in Bächtold & Guedj, 2014; Besson, 2014; Levrini, 2014). It can also foster discussions about NOS (as seen in Develaki, 2012; de Berg, 2014a; Taylor & Hunt, 2014; Fouad et al., 2015; García-Carmona & Acevedo-Díaz, 2017), including its epistemic nature (such as theories, models and evidence), inquiry aspects (such as methods, experimentation and instrumentation, data collection and interpretation), and its social-institutional dimension (such as peer reviewing processes, certification of knowledge, collaborative work, and ethical and financial aspects of science).

HOS has also the potential to humanise scientists by showing that scientific work is carried out by regular people working in a community that is also connected with the external public. This idea is related to promoting positive attitudes towards science and scientific careers, and the 'public understanding of science' regarding the image of science and scientists. Here, among the benefits of introducing HOS into science education, authors (Matthews, 1995; Hodson, 1999; Kampourakis & McComas, 2010; Kampourakis, 2013; Krugly-Smolska, 2013; Allchin, 2014; Sarukkai, 2014; Fouad et al., 2015) highlight its impact on students' understanding of the scientific enterprise as a dynamic, fallible and negotiated community.

Thus, a historical work can foster different aims of science education. Particularly, HOS can become a valuable tool to the analysis of a particular knowledge in its original context (its 'horizontal dimension') and then to promote its subsequent generalization (its 'vertical dimension') (Compiani, 2007). The study of the historical context of a scientific topic development does not mean then to simply move students to a different reality (in space and time). In fact, it involves allowing them to explore more widely the differences and similarities between scientific processes happening at different moments and places, generalizing and contextualizing simultaneously the information accessed. This historical way of working may promote the development of abilities of synthesis, analysis of changes and trends (Compiani, 2007; Talanquer, 2011).

Another relevant aspect of HOS is its potential for promoting integration of science with other school subjects and topics, since it can foster the understanding that science is the result of different interactions among its own areas of knowledge (Physics, Chemistry, Biology, Biochemistry, Cosmology, Biophysics, Geophysics, etc.) and also with other fields (economy, politics, ethics, moral, media, environment, society). This comprehension can generate new suggestions for teaching in a cross-curricular direction, since the latent interdisciplinary feature of science is demonstrated by HOS as crucial for numerous and important advancements, including in the twenty-first century (Jordan, 1989; Justi & Erduran, 2015).

This short review about the main benefits HOS can bring to school science seems to reveal its capacity to generate a critical and open-ended way of learning about science and scientific culture. It would be naïve to think, however, that this introduction can be easily done by any teacher in different contexts. This is especially true when top-down efforts are made, without a concern about the several aspects involved in science teachers' responsibilities and classroom realities (Levinson & Thomas, 1997; Ryder & Banner, 2013; Ryder et al., 2018). As pointed out before, different countries have been experiencing difficulties in implementing these innovative activities, resulting in the conclusion that there might be some important obstacles to be considered in the use of HOS in school science. Therefore, in the next subsection, I will explore some of the debates surrounding the main hindrances and concerns that arise from the use of historical approaches in school science.

2.2.3. Bringing HOS to school science: obstacles

While the implementation of HOS in science lessons in different levels of teaching has been advocated by several science educators and researchers, there are other groups involved in this debate who have been questioning the efficacy of this approach in school activities, especially in relation to what should be taught as part of school science. Researchers such as Thomas Kuhn, Martin Kline and Stephen Brush argued, for instance, that the introduction of HOS in science 'training' could damage the understanding of scientific paradigms (to them, the main purpose of scientific education), creating tensions between learning science and learning about science (Kuhn, 1977/2011). Their general idea is that learning about HOS can lead students to the perception of science as embedded by tentativeness, mutability, and lack of consent, damaging their interest in scientific careers and even creating an antagonistic atmosphere towards scientific knowledge.

This argument could only make sense if our concerns about science teaching and learning were related exclusively to the scientific 'training' or, in other words, to the education of future scientists and technicians under a technicist perspective, and to the teaching of solely scientific content and practical skills. Even so, I would argue here that HOS is an important tool also to professional education, since it can enable scientists to think critically about theirs and others' scientific activities and communication, including the complexity and uncertain aspects of contemporary science, as also argued by Matthews (first in 1995 and again in 2014a).

Other criticisms against the introduction of HOS in science education are presented by Donnelly (2004) and de Berg (2014b). Among them is the fact that there are essential epistemological and purposed differences between science education and HOS; that is, these fields operate under different paradigms and purposes. To illustrate that de Berg (2014b, p. 318) argues that "while chemistry, like other sciences, abstracts, idealises, models and simplifies, history attempts to capture the richness of past events in their complexity". Nevertheless, he also claims that a positive balance amid these two approaches can be achieved in science lessons, since, citing Niaz and Rodriguez (2001), "history is not something that is added to chemistry [and science in general]. It is already inside chemistry as it were." (de Berg, 2014b, p. 318).

Other debates around historical approaches seem to arise from a more pragmatic point of view about school science, such as the fact that knowledge produced by historians of science cannot be used directly in science lessons due to its complexity and depth, so there is always the need for adapting this scholarship (Basu, 1999; Forato et al., 2012). Here there is a danger of over-simplifying the process of knowledge construction to the extent it could lead to the conclusion that scientific development is relatively straightforward. Another issue highlighted by many researchers (de Berg, 2014b; Klassen & Froese Klassen, 2014; Taylor & Hunt, 2014; Forato et al., 2015) is the introduction of HOS in science lessons through anachronistic approaches: a distorted history, where “history of science is viewed in light of current knowledge” (Klassen & Froese Klassen, 2014, p. 1520). According to Forato and colleagues (2015, p. 2), this approach, by attempting to simplify history to students, tends to build a “naïve or faulty view concerning the scientific endeavour”, leading to the teaching of something that is neither science nor HOS.

There are also concerns about how to assess the learning of both scientific and historical aspects related to a HOS-based activity, since assessment is a relevant part of the educational process (de Berg, 2014b; Henke & Höttecke, 2015). After years of work with teachers, Henke and Höttecke (2015) argue that they still feel insecure in designing and implementing forms of assessment to evaluate learning after HOS activities, mainly due to the absence of orientation on how to do it.

These latter practical concerns seem to be more related to how the implementation of HOS in science lessons can be done than to issues about the reasons for doing it. Therefore, we can argue that these problems can be overcome, to some extent, if cautious work is carried out to stimulate and aid teachers in the introduction of different approaches into their practices. The main possibilities and characteristics of this ‘cautious work’ will be further explored in the empirical phases of this investigation, especially in chapter 6.

Nevertheless, despite this careful preparation of HOS-based resources, obstacles for implementing new routines in science lessons can still be numerous, as shown by different research in the field (Höttecke & Silva, 2011; Ryder & Banner, 2013; Levrini, 2014; Henke & Höttecke, 2015; Ryder et al., 2018). For instance, some deeply rooted conceptions about science teaching appear as barriers to the introduction of HOS, such as the preference for content-driven activities and evaluations, and the notion that historical scientific ideas are outdated or wrong, not being the modern portrait of actual science (Henke & Höttecke, 2015). Furthermore, some teachers' common attitudes towards innovation in science education practices need to be overcome, as emphasized by Levrini (2014) when presenting the results of a European investigation about HOS and school science. Amongst these attitudes there are: using personal criteria to choose one approach over another; mixing new and old pedagogical practices; and trying to use new pedagogical proposals to solve disciplinary/behaviour issues.

This complexity of the educational system and teachers' existing practices are relevant points to be considered and understood before the development of different teaching proposals, either through curricular revisions or specific empirical projects. Particularly in the case of historical approaches, the results of a European project (‘HIPST: History and Philosophy in Science Teaching’) carried out by ten research groups showed that HOS is often used as an anecdotal introduction to a specific topic or content (as a historical background) and is rarely seen in science textbooks (Höttecke & Silva, 2011). These and other empirical findings are related by the authors to some general obstacles of implementing HOS in science lessons (pointedly in Physics teaching): the culture of teaching science/physics; the lack of historical materials available for teachers; teachers' skills, attitudes and beliefs; and institutional frameworks of science/physics teaching (e.g. curriculum development).

The culture of teaching science can be understood as “constructed by noticeable features which embrace teachers, who are immersed in that culture, and strongly affects their curricular decisions and instructional behaviour” (Höttecke & Silva, 2011, p. 296). In their project, the authors found that the culture of teaching physics was related to, in general: valuing a definite knowledge (there is only one way of answering a problem); students are not supposed to express their own ideas and need to memorize scientific facts (no creative learning); teacher-centred lessons; and strong relation of identity between the teacher and the discipline. Therefore, this culture is linked to a view of science education where the products of science are more relevant than its processes.

In addition, institutional structures, illustrated by curricula and assessment constraints, seem to stimulate innovation often in a generic way, through theoretical documents, with few reflections about practical implications of innovating in education, such as the development of textbooks and other teaching resources and continuous professional development. In this case, activities using HOS appear to be relevant, but simultaneously dispensable (Höttecke & Silva, 2011). This present study will then explore these practical aspects behind introducing innovation into science lessons, aiming at working within the curricular and assessment boundaries, but also moving beyond the sole production of theoretical proposals.

Considering the complexity of educational systems and their obstacles to innovation and change appears to be the first step to properly bring HOS to school science. It seems obvious that overcoming all these obstacles demands effort from different actors within this system, such as teachers (who could work collaboratively to reflect about their own subject culture, while also creating different practices), science educators (offering support for teachers and schools interested in implementing innovative activities), institutional workers and policy makers (Höttecke & Silva, 2011; de Berg, 2014a).

Therefore, considering that my main objective with this study was to implement NOS teaching activities based on HOS, the initial steps of my empirical research were dedicated to an 'Exploratory phase', which aimed at understanding the realities of the participant schools, their science teachers and practices before starting the development of these resources[12]. In addition, I developed the subsequent 'Implementation phase' with the help of a participant science teacher through an extensive period of collaborative work, taking into account external forces (such as the intended curriculum and end-of-year examination) and the teacher's reality and personal goals when engaging with this specific experience[13] (Ryder et al., 2018).

2.2.4. Bringing HOS to school science: lessons from past experiences

Designing HOS resources to be used in school science often raises an important question: how to do it? And using which materials? And how can the teacher take ownership of this way of working and run it independently?

According to Pessôa Jr. (1996), there are several practical approaches to the use of HOS in science lessons, being the most prominent: Internalist[14]; Externalist[15]; Reading of original documents[16]; Historical scientific instruments[17]; and Biographical[18]. Although the uses of HOS in science education can be divided so rigidly, the emergence of the sociological and psychological perspectives in the field of HPSS in the 1970s and 1980s has to some extent overcome these distinctions, allowing for their integration. Aided by these new approaches, scientific knowledge was then being analysed from the point of view of its development and all inherent factors, such as its internal and external relations, and experimental aspects. In summary and as previously mentioned, scientific knowledge started to be seen as a product of the

[12] More details about this research phase will be explored in chapters 4 and 5.

[13] More details about this research phase will be explored in chapters 4, 6 and 7.

[14] Focusing on the internal dynamics of science, its paradigms, models, laws and theories, ways of operation.

[15] Based on the study of a scientific concept or theme within the social context where it was developed, including the analysis of social-cultural aspects.

[16] Encompasses the reading of original texts produced by scientists (primary historical sources) to analyse historical data, experimental design, debates, etc. An interesting discussion about this approach can be found in Sutton (1992).

[17] It has an experimental focus and includes the study of the history of a specific instrument, such as telescopes, microscopes, spectrometers, and its relation to a wider History of scientific development.

[18] Encompasses the development of a biographical study, examining scientists' ideas and their importance to science.

culture in which it is developed and operates, which impacted the way historical narratives about science were being built and introduced into school science (Kelly et al., 1993; Matthews, 2014a).

Independently of the chosen approach to the use of HOS in school science, researchers tend to agree that this needs to consider both the historiographical and pedagogical domains (Forato et al., 2012; 2015). In other words, the design and implementation of such strategies often require a commitment to pedagogical (to overcome the cultural, material and institutional obstacles discussed in the last subsection) and historiographical (to critically produce knowledge about HOS targeting the general public) works. Forato and others (2015), for instance, advocate for a continuous but gradual approach, where some few ideas about HOS (and NOS) are worked with and by the students each time. This could foster a wider and deeper understanding of the topic, without overloading teachers and students with too much, and yet oversimplified information.

Likewise, Allchin (2004), Höttecke and Silva (2011) and Ideland (2018) discuss the importance of paying attention to the context behind the historical narrative. They argue that science textbooks and other materials traditionally employed by science teachers usually contain accounts of HOS only in an illustrative way, and can end up misleadingly informing teachers' practices regarding these historical narratives, such as stories about Newton's apple or Galileo's relationship with the Church [see Dagher & Ford (2005) on biographies of scientists for children and Ideland (2018) and Kelly (2018) on historical narratives in science textbooks]. Similarly, results from the European HIPST project mentioned in the previous subsection showed that in Europe HOS is often used as an anecdotal introduction to a specific topic or content (as a historical background) and is rarely seen in science textbooks in a different way (Höttecke & Silva, 2011). Some classroom-based research (Forato et al., 2012; Gandolfi, 2017) also showed how historical accounts, when employed in an anecdotal and romanticised fashion, can lead to misunderstandings about the nature of scientific work and the scientific community (Allchin, 2014).

In order to aid teachers in this introduction of HOS into school science while also avoiding the obstacles and pitfalls of this approach, several recent works in the field of Science Education have been published. In 2014, for instance, an international handbook (Matthews, 2014a) was edited to assemble different proposals, with many projects in areas like Chemistry, Biology, Physics, Mathematics, and Earth Sciences.

Some examples included the use of historical case studies to promote debates about the importance of testing theories and the place of empirical analysis, mathematical thinking and measurements in the development of scientific knowledge (Matthews, 2014b); or to discuss and reflect about the social and technological contexts of the historical development of a scientific topic, such as the Industrial Revolution (Besson, 2014). There were also works involving the use of argumentation for discussing historical and contemporary socio-scientific issues, such as GMOs (Gericke & Smith, 2014), and of Information and Communications Technology (ICT) tools and narratives to discuss controversies about atomic structure, models, speculation and contradictions in the scientific culture (Chamizo & Garritz, 2014).

The European HIPST project also produced several proposals, which were applied, reconfigured and reapplied in different school levels and countries, involving the work of teachers and researchers. The results of this project, including guidelines for the 32 historical proposals developed, are available on the group's webpage[19]. Similar examples of empirical experiences with teaching through HOS can be found in other research groups' webpages[20] and in several publications (e.g. Abd-El-Khalick & Lederman, 2000; Develaki, 2012; Guerra et al., 2013; Allchin et al., 2014; Gurgel et al., 2014; Fouad et al., 2015; García-Carmona & Acevedo-Díaz, 2017; among many others). Among the different strategies for the use of HOS commonly found in this literature, Henke and Höttecke (2015, p. 350) summarise:

> Reading, analysing and discussing original historical research papers, lab-diaries or technical reports [...]; Telling rich historical anecdotes, short stories or interactive vignettes accompanied by conceptual, methodological and philosophical reflection [...]; Conducting historical (thought) experiments or replicating actual laboratory procedures, tracing the development of scientific methods, concepts and theories [...]; Combinations of the above strategies within the context of detailed historical case studies spanning multiple lessons […].

2.2.5. Final remarks

After reviewing and reflecting about the main possibilities and general obstacles that can arise from theoretical and applied projects around the use of HOS in school science, some remarks are relevant at this point. While this approach seems to be useful to address important aims of contemporary science education, such as the understanding of NOS, it is worth noting that the essential contribution that HOS can make to science teaching and learning is not related to the teaching of 'history of

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[19] http://hipstwiki.wikifoundry.com/page/links

[20] See, for instance:

https://www.storybehindthescience.org/

http://shipseducation.net/

science’ as a new curricular subject, which would only bring new and distinct content to already packed science lessons.

On the contrary, HOS should be integrated into these lessons as a means of helping students to learn and reflect about the processes and products of the science they are currently learning. In other words, HOS resources should be built to balance the teaching of standard content of science and the comprehension of its methods, inquiries, ways of producing and communicating knowledge, and relationships with different domains. This strategy can stimulate students to build a wider understanding of the scientific culture, going from merely consumers of science in their everyday lives to critical analysts of this culture, as argued by Peter McLaren in Barton (2001) and by Ideland (2018).

Nevertheless, the analysis of the literature in this field has shown that implementing new and innovative strategies in school science is neither simple nor immediate. Every innovation intended for a complex system such as Education must take into account the skills and culture of the participants and of this system itself. Therefore, it is an effort that demands collaborative and active work between teachers, researchers and institutional framework, including the design of more teaching resources to support long-term practices.

In addition, the use of these new approaches is also expected to produce a change in classroom and subject cultures, forcing the boundaries of more common ways of teaching science, since they may involve open-ended discussions, the teacher being a moderator and the students actively presenting their ideas. This study inserts itself exactly in this scenario of expansion of the use of HOS to integrate NOS discussions into school science, being developed through a collaborative work with a science teacher and also taking into consideration curricular demands, time constraints, regular assessment, pedagogical possibilities, and class realities.

On a final note, while the arguments for the use of HOS in school science tend to highlight its potential to promote discussions about how science works (NOS) and to ‘humanise’ the field by challenging traditional views about scientists and scientific work, some of these ideas have been recently questioned (Jegede & Aikenhead, 1999; Krugly-Smolska, 2013; Sarukkai, 2014; Ideland, 2018; Kelly, 2018; Lee, 2018), with special attention to which historical contexts are being employed by these proposals. More than 20 years ago, Dennick (1992) and Hodson (1998) were already discussing how school science resources, such as textbooks, often downplay or completely erase historical contributions to science and technology made by different people in different cultural contexts, and Ideland’s (2018) recent investigation of Swedish science textbooks yielded similar results.

To illustrate that, two large recent research projects, the European HIPST already mentioned here and the 'Story Behind the Science'[21] carried out in the USA (Clough, 2011) developed more than 50 'historical cases' (teaching resources and guidelines) to aid the introduction of HOS into school science. Among these cases, only three included some mention and/or discussion about contributions to the topic by non-European and non-USA-based scientists or communities (namely: the history of cooling and refrigeration in Africa and India; Muslim medieval science and the concepts of image and vision; Muslim medieval science and ideas about motion).

As argued by Erduran (2014), Sarukkai (2014) and Ideland (2018, p. 795), the constant use of only European scientists from HOS ("the narratives of few white men") has the danger of propagating a historically unrealistic image of modern science as exclusively a European achievement. In this scenario, the lack of diversity in these proposals for the use of HOS in school science can result in the portrayal of a specific image of science, scientific work and community that only fosters a biased humanisation of science and scientists.

Beyond aiming at introducing NOS through the use of HOS in regular science lessons in secondary schools, this study advocates an intercultural approach towards the choice of historical narratives to be employed during this experience. This intercultural perspective, to be further explored in the next section, endeavours to develop historical cases that encompass a broader view of HOS, including contributions from different people and communities to the development of scientific knowledge throughout our history.

2.3. An intercultural perspective of HOS to Science Education[22]

While the introduction of NOS into school science through historical cases has received a great amount of attention in the past decades, one specific topic seems to have entered this debate more recently: what do we consider as science and scientific knowledge and, therefore, what should we include in these lessons about NOS? In this project I advocate the incorporation of HOS in science education to promote the understanding of the NOS, but how can this be connected to historical accounts about scientific development in different cultures and societies throughout their history? And how modern science, the core aim of most science curricula, can encompass these reflections?

[21] See https://www.storybehindthescience.org/

[22] This section relies mainly on two papers previously published as part of this doctoral research (Gandolfi, 2018a; Gandolfi, 2018b).

These initial thoughts about scientific development are rooted in post/decolonial[23] and postmodern studies of science and in the own history of modern science, being debated from sociological, cultural, historical, and philosophical standpoints. In this study, it is not my main purpose to enter deeply in these debates, though it is my aim to reflect on these topics to understand their implications and possibilities to teaching science from an intercultural perspective, in which learning about NOS acquires a wider and more diverse meaning.

2.3.1. Modern science and postmodern studies: a brief overview

Postmodern studies are the result of philosophical, cultural and political movements developed towards the end of the twentieth century as a counter-modernist approach. They sought to be a response to Modernism and its 'project of modernity', which included universalist elements, objective rationalism, progressiveness, and the rejection of particularistic views of nations, diluting the differences between nations and people, creating 'citizens of the world' and transnational forms of politics (Habermas & Ben-Habib, 1981).

The initial purpose of the postmodern movement was to build a critique of this idea of 'citizens of the world', focusing mainly on the violence of globalisation processes that, according to some postmodernists, tend to blur the particularities among cultures around the world, while also imposing specific views from very few dominant cultures onto the rest of the world (Ideland, 2018). By advocating against Modernism, they argue that "all modern social theory springs from an uncritical Enlightenment faith in science and reason and leads to 'grand narratives' that legitimate political repression and distinctively modern forms of social and cultural oppression" (Antonio & Kellner, 1994, p. 1).

Postmodern studies have received several critiques from different philosophers and sociologists since the 1980s (Antonio & Kellner, 1994; Dawkins, 1998; Nola & Irzik, 2005), especially in relation to its link to extreme relativism[24]. According to these critics,

[23] Postcolonialism and Decolonialism are two traditions of thought surrounding the historical relationships between colonies and colonisers. While having arisen from different disciplines (Cultural Studies in the case of Postcolonialism, and Critical Social Theory in the case of Decolonialism), geographical contexts (Middle East/South Asia and Latin America, respectively) and time frame of analysis (nineteenth/twentieth centuries, and fifteenth century onwards, respectively), they generally adopt similar approaches to the study of the "insularity of historical narratives and historiographical traditions emanating from Europe" (Bhambra, 2014, p. 115; Huguet, 2015).

[24] Relativism, as opposed to universalism, is a concept that denies an absolute truth and defends the recognition of the existence of different truths, which rise from different values and contexts (Cobern & Loving, 2001).

an extreme postmodern (relativist) position can lead to the acceptance of an ‘anything goes’ scenario in different fields, such as Politics, Human Rights, Ethics, Media, and in Science and Technology (Wolpert, 1997; Wilber, 2017).

Nevertheless, some important reflections have arisen from the postmodern argument, mainly because it opened a space for the consideration of socio-cultural, economic and political aspects involved in the production of knowledge (including scientific) by different cultures (García Canclini, 1990; Hall, 1992; Ideland, 2018). The postmodern critique was then closely connected with the already mentioned socio-cultural studies of scientific work (e.g. SSK and Laboratory Studies), which promoted the view that the natural world, the production of scientific knowledge and social-cultural aspects (including politics) cannot be dissociated (Latour, 1993).

Within this approach towards scientific development, some non-dominant systems of knowledge were not simply constituted by an instrumentalist view of the natural world but were also involved in developing “systematic empirical and theoretical practices of coming to understand how the world around us works” (Harding, 2008, p.16). Through these lenses, a pathway was created to acknowledge that societies and cultures other than the traditional European ones, in different moments, could (and can) also develop scientific practices (Shiva, 1993; Harding, 1994; S. Hansson, 2018; Ideland, 2018). This perspective has led to the consideration of how different communities (e.g. local communities in India or the Aztecs in the Americas) can engage (or have engaged) with production of knowledge about the world and how they influenced and impacted each other.

These specific views on scientific development stemming from postmodern studies were generally a target for critics, especially during the ‘Science Wars’ in the 1990s[25]. They were suspicious of some extremely relativistic statements that equalise all systems of knowledge (such as modern, indigenous, ecological), giving all of them the same epistemic status (including correctness) regarding what can be considered a valid account of the natural world, and diminishing the authority of modern scientific knowledge[26]. These authors (Haack, 1996; Wolpert, 1997; Siegel, 1997; Nola & Irzik, 2005; Mackenzie et al., 2014; Matthews, 2014c) argued that not all ways of interacting and making sense of the natural world can be considered equally valid and correct. Although most of them are interested in identifying regularities, developing practices and predictions (which would constitute a ‘system of knowledge’), they are not always

[25] An intensive debate between postmodern (‘socio-constructionists’) and modern (‘realist’) research groups in the field of STS carried out especially in the USA.

[26] An interesting recent piece by Bruno Latour, one of the most prominent participants in these debates on the side of the postmodern group, considers the impact of postmodern ideas on scientific authority and the ‘post-truth’ scenario: https://www.nytimes.com/2018/10/25/magazine/bruno-latour-post-truth-philosopher-science.html

concerned with developing explanations about these phenomena. In summary, these authors tend to agree that science can be understood as a system of knowledge which, besides identifying regularities, developing practices and making predictions, is equally interested in building consistent theories and explanations about the natural world.

Despite their opposed ideas about what can or cannot be considered science, these two groups seem to have reached at least some degree of agreement specifically in relation to the origins of modern science[27] (Rose, 1997; S. Hansson, 2018). By acknowledging that ‘universal’ does not mean free of context, beliefs and negotiations (Siegel, 1997; Nola & Irzik, 2005; Matthews, 2014c), the critics of more relativistic studies of science also recognise that “the history of science shows how dependent European science has been upon the achievements of non-European cultures” (Matthews, 1995, p. 192; Rose, 1997).

According to Harding (1996) the consideration of the contributions from different cultural contexts and traditions to modern science has shifted the understanding of science from solely an internalist perspective to the acknowledgement of its externalist features (i.e. relations with politics, economy, religion, among others) and of the relationship between these two. In this scenario, the already mentioned changes in during the 1970s and 1980s, which are intertwined with these postmodern perspectives, heavily influenced the way this field understands the historical development of modern science (Rose, 1997; S. Hansson, 2018).

2.3.2. Global History of Science

Among these new socio-cultural perspectives to the study of modern science, there is the ‘Global History of Science’ perspective (Roberts, 2009; Elshakry, 2010; Fan, 2012). This approach is grounded on the idea that modern science is in fact a product of material and cognitive exchanges, appropriations, and collaborations between different cultural traditions, and of the circulation of diverse types of knowledge around the world, all promoted by historical and geographical contexts (such as the trade in the Silk Road, and European colonising and imperialist projects). This approach to HOS is interested mainly in the following questions:

> 1. How can sources which are variable with respect to genre, materiality[28] and origin be read alongside each other? Can such

[27] Called by many researchers as ‘Western’, ‘European’ or ‘Mainstream’ science (Shiva, 1993; Harding, 1994; 2008), opposed by ‘non-Western’ or ‘non-mainstream’ science. Other groups, especially in Latin America, prefer ‘Central science’, opposed by ‘Peripheral science’ (Filgueiras, 2001).

[28] As understood in Anthropology, that is, artefacts and other forms of cultural production.

> cross-contextualisation of archival and material remains provide a different narrative of the global in science?
> 2. How was science consolidated as a form of intellectual property as a result of global processes? How did globalization generate a sense of what was unscientific, and in particular, how did it define and come to terms with the 'indigenous'?
> 3. How have cultures and traditions been defined through science? How has the globalization of cultural forms impacted on the placement of science in the global? What is the relation between the globalisation of science and imperialist science?
> 4. What pathways has science travelled through, and can this be elucidated in relation to the pathways taken by archival and material remains? How did science become bound to empires and nations, and how have global narratives been missed by past scholars? (Exploring traditions, n.d.).

As argued by Fan (2012, p. 251), "[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". Thus, according to Roberts (2009) and Elshakry (2010), Global History of Science offers a way out of the epistemological problems posed by extreme relativistic approaches towards HOS (such as those raised by the critics of postmodern studies). This is done by avoiding a comparative/dichotomous approach (one that focuses on similarities and difference between systems of knowledge) and promoting instead an understanding of modern science as a dynamic product of several cultural and economic encounters and exchanges (forced or not) among different communities.

In her reflexive paper about issues within the field of HOS, Orthia (2016) advocates a 'big picture' approach to HOS, in which micro and macro (or 'global') studies about scientific developments can bring together the best of both worlds: while a micro perspective would focus on localised, specific achievements, the macro perspective would then establish a connection between this particular case and a social, cultural, political and economic moment within history. According to the author, this "contextualisation of science at a global stage" (Orthia, 2016, p. 363) does not mean understanding science itself (that is, scientific knowledge) as global (a 'universalist' perspective) but understanding its development as a result of global connections. This can result in the construction of a "more pluralist, more historicist, more localised, less universalist picture of science" (Orthia, 2016, p. 363), while also recognising the limits of these global collaborations and the place of colonising processes in this history. Adding to that, Lee (2018, p. 491) argues that a Global

History approach has the potential to portray science and technology as “products of cultural interactions within the world context rather than as Western products developing into a universal world culture as if they are independent of other aspects of the humanities.”

The adoption of a model of HOS studies such as the ‘Global History’ means then recognising it as a political and ideological field of research that produces knowledge about the history of scientific development through different lenses (Orthia, 2016). In this scenario, we need to acknowledge that any proposal involving HOS, such as those used in science education, indicates a specific positioning in relation to the question ‘which HOS?’. Therefore, advocating the use of HOS in school science entails a decision regarding how the historical cases and narratives will be built, which will impact the images of science (NOS) and scientists portrayed by these resources.

2.3.3. Bringing Global History of Science to school science: an intercultural proposal

The debates from postmodern studies addressed in subsection 2.3.1 impacted views about science and scientific communities (Rose, 1997), and thus the different ways we may conceptualise NOS. Although the word ‘science’ is often understood, including in Education, as modern science, postmodern studies challenged that mainly by advocating the acknowledgement of different ways of reasoning about the natural world, resulting in the field of Multicultural Science Education (MSE). Angela Calabrese Barton, for instance, raises the issue about how other cultures and places are portrayed by school science in her interview with Peter McLaren (Barton, 2001, p. 853):

> I can link your point about distancing science from class interests to, on the one hand, how we ‘teach’ about developing countries in science class. The rare moments when developing countries are described in typical science textbooks tend to be in relation to disease and pollution (i.e., the typical biology textbook picture of the poor African woman with a goiter).

In addition, as discussed by Peter McLaren in this interview, the relationship between capitalism, power and production of scientific knowledge has also deeply influenced the way most countries view science education. According to McLaren, “the marriages between capitalism and education and capitalism and science have created a foundation for science education that emphasises corporate values at the expense of social justice and human dignity” (Barton, 2001, p. 847). In other words, as found by

Ideland (2018) in her investigation of Swedish science textbooks, solely utilitarian, neoliberal and triumphalist views about science are advanced by most curricula and practices in science education without critical reflection or acknowledgement of its limitations, implications, and political, economic and ethical commitments: “what I am suggesting is that we find ways to critically examine the relationship between corporate power and the knowledge we label for our students as ‘objective’ and ‘true’” (Barton, 2001, p. 850).

It is worth noticing here that this ‘critical examination’ of science advocated by McLaren holds a close connection with teaching and learning about NOS and with the avoidance of dogmatising science and reinforcing scientism (Gasparatou, 2017). In this context, Erduran (2014) and Ideland (2018) argue that some specific approaches to HOS that take into account this ‘critical examination’ of historical narratives can foster a wider understanding of NOS, including aspects of social justice, oppression and cross-cultural interactions, exposing “the many often ignored ‘faces of science’” (Erduran, 2014, p. 106).

Nevertheless, the debates between postmodernists and their critics are also present in the field of Science Education, with several controversies between those who advocate a more critical and cross-cultural perspective of science and those more sceptical about the real benefits of these ideas to science lessons. Those who criticize the legacy of MSE to science education argue that not all systems of knowledge are philosophically and epistemically equal and that presenting them to students as such can promote a dangerous idea that all forms of reasoning can then be accepted as valid explanations of the natural world including, for instance, Astrology and Creationism (Wolpert, 1997; Irzik, 2001; McCarthy, 2014).

Moreover, some relativistic resources designed for science lessons to address knowledge from minority groups can sometimes present distorted views about these systems of knowledge (this is something that can also happen, obviously, with the universalistic approach), mainly by using too radical and biased revisionism of HOS (Cobern & Loving, 2001; Ortiz de Montellano, 2001). Furthermore, McCarthy (2014) also draws attention to the fact that some of these resources tend to ignore knowledge from modern science, focusing only on other systems of knowledge. Here she argues that the purpose of social justice (advocated by both groups) should mean ‘science for all’ (in relation to the aim for scientific literacy for all citizens) and it should give all students the opportunity to also learn the widely used modern science and not only local and/or cultural knowledge. According to El-Hani and Mortimer (2007, p. 679) not teaching modern science “can harm students' development in their social environments, since it will alienate them from a quite powerful way of knowing”.

Currently, many authors (Rose, 1997; Jegede & Aikenhead, 1999; Irzik & Irzik, 2002; Nola & Irzik, 2005; El-Hani & Mortimer, 2007; Horsthemke & Yore, 2014; Mackenzie et al., 2014; S. Hansson, 2018) have been arguing for a middle-ground approach to school science that moves away both from an acritical view of science and from extreme relativism, acknowledging the importance of modern science to our lives nowadays while also including reflections about its cross-cultural aspects, limitations, positive and negative features. This perspective considers the needs for teaching and learning about modern science while also understanding its intercultural roots, looking at how different, non-mainstream ideas have also contributed to our current knowledge about the world (Rose, 1997; Svennbeck, 2001; S. Hansson, 2018).

This strategy of uniting the regular teaching of modern science with some of its intercultural aspects can help teachers to engage with their increasingly multicultural and heterogeneous groups of students found in urban schools. According to Jegede and Aikenhead (1999, p. 53), this working between (but not with) “the total assimilation into Western Science and the rejection of Western Science” could be a realistic and practical pathway for important ideas from the field of MSE to be addressed, but only if careful considerations are taken about how these connections will be made, especially in relation to the cultural and historical revisionism mentioned above (Cobern & Loving, 2001; Ortiz de Montellano, 2001; S. Hansson, 2018).

In this scenario, different authors (Hodson, 1999; Krugly-Smolska, 2013; Sarukkai, 2014; S. Hansson, 2018; Ideland, 2018; Lee, 2018), informed by contemporary research from the field of HOS, defend its potential to foster a more historically and culturally informed view about the diversity behind where scientific knowledge has come from and how it is produced. Besides promoting learning about NOS, HOS can also challenge hundreds of years of preconceptions and biased views about scientific communities, essentially by showing that different types of cultures, people and societies are (and have been) connected with scientific work (Erduran, 2014; Ideland, 2018).

Hodson (1999), for instance, discusses how HOS can help to overcome some distorted views about NOS, such as the notion that science is an exclusively Western and post-Renaissance practice, by using more examples of scientific work carried out by different cultures. He suggested some topics (such as medicine, astronomy and agriculture from Indian, Chinese, African and Arabic cultures) that could promote students’ understanding that different communities around the world have their own traditions of production of knowledge about nature.

This type of approach, closely connected to ideas of ‘cultural pluralism’, usually tends to acknowledge that several societies and cultures other than the European ones also developed their own scientific practices at different historical periods (Pomeroy, 1994; Krugly-Smolska, 2013). This idea, however, is challenged by some critics (Nola & Irzik, 2005; Matthews, 2014c), who are suspicious of the inclusion of extremely relativistic and tokenist examples into science lessons and of their use as merely 'adds-on' to the regular curriculum, as stand-alone examples often disconnected (independent) from each other.

Another suggestion for the introduction of a more diverse view of HOS into school science is through an intercultural and dynamic perspective about the development of modern science – an 'intercultural model of HOS' (Pomeroy, 1994; Sarukkai, 2014; Lee & Kwok, 2017; Lee, 2018). Contrary to the previous model, which is often related to more relativistic (and sometimes tokenist) perspectives, this intercultural approach arises from the Global HOS perspective (Roberts, 2009; Elshakry, 2010; Fan, 2012) discussed in the previous subsection. It is then based on the acknowledgement that we indeed have a widely spread (modern) way of doing science, which seems to generally solve our problems and questions about the natural world, but it also highlights the intercultural aspects involved in the development of this modern science through the critical lenses of post/decolonial perspectives (Erduran, 2014; Ideland, 2018).

Lee (2018, p. 503), while proposing this approach to the teaching of science and technology, describes it as "[accepting] modern science as a unique development in the western cultural context, while recognizing the contribution of multicultural knowledge systems in understanding and harnessing nature, which, through technology diffusion, influence technological and scientific development in other cultures." Closely connected with Orthia's (2016) discussion about the 'big picture' approach to HOS in the previous subsection is the characteristic of this intercultural model of situating specific cases (e.g. variolation) within a wider cross-cultural perspective (i.e. knowledge exchanges between different communities of practice in China, Turkey and Europe), moving constantly between micro and macro contexts.

Take, for instance, the topic of magnetism, found in most science curricula. The use of an intercultural approach to HOS when planning lessons around this content can connect local uses of magnetic properties by different communities in history (e.g. Greek, Indian, Chinese, European) and look at how material (e.g. sources of magnetic materials), knowledge and technology exchange among them enabled, for instance, the development and spreading of the compass as a navigation tool, leading to important historical global events such as the Great Navigations. In turn, knowledge about this instrument (i.e. how it works, why it works like that) and Earth's magnetic properties allowed for a better understanding of magnetic fields and their main features, whilst these technological advances fostered even more circulation of knowledge and resources, with great impact on access to medicines and minerals, for example.

According to Sarukkai (2014), this model (which he calls ‘multicultural origin of science’) can bring a more diverse view of science to science lessons, challenging traditions in HOS that “led generations of students in non-Western societies to believe that their cultures have had no contribution to the science of the modern world” (Sarukkai 2014, p. 1696). Likewise, different authors (Pomeroy, 1994; Erduran, 2014; Sarukkai, 2014; Gondwe & Longnecker, 2015; Ideland, 2018; Lee, 2018) highlight its possible impact on students' understandings of the scientific enterprise as a more diverse space, since “students from different backgrounds will be able to relate more easily and proudly to science and scientists if they are able to study the contributions of people of diverse cultures to the body and process of science which we now accept” (Pomeroy, 1994, p. 56). In this context, Sarukkai (2014) and Ideland (2018) argue that this strategy could also enhance students' positive attitudes towards science and scientific careers, essentially by showing them that different types of cultures, people and societies can engage with scientific work, instead of promoting a view of the “practice of science, and the science-literate person, as connected to a certain place: the West” (Ideland, 2018, p. 784).

Additionally, this intercultural approach can also foster the learning of NOS in a wider and more holistic way when compared with most proposals found in the literature in the field, especially in relation to the view of science and of scientific communities from a social-institutional perspective (or the ‘non-epistemic aspects’ of NOS). Its potential, as exemplified above with the magnetism topic, resides in the fact that the whole use of HOS in science lessons is now informed by notions of collaboration, negotiation and adaptation of scientific knowledge, exploitation of and power-struggle regarding natural resources and knowledge, ethical, economic and political aspects of science, among many others (Erduran, 2014; Ideland, 2018).

The choice of using this intercultural HOS model while teaching about NOS addresses then a recent debate in the field of Science Education regarding the different aspects of NOS being introduced by proposals made available to teachers: as argued by Erduran (2014), Aragón-Méndez, Acevedo-Díaz and García-Carmona (2018), and Ideland (2018), the majority of these resources tends to focus mainly on epistemic aspects (of more philosophical nature, such as theories and explanations, modelling, methods and experimentation), while only lightly involving the non-epistemic (or social-institutional) ones. By being based on a social and intercultural perspective of HOS, this intercultural approach fosters a scenario where explicit discussions about non-epistemic aspects are also important to the understanding of scientific work, with both epistemic and non-epistemic ideas being intrinsically linked (and possibly inseparable from each other) and integral to the discussions carried out with students.

Nevertheless, few studies have been developed to go beyond advocating an intercultural model of HOS by actually proposing ways to schematise and operationalise this approach within school science (e.g. suggestions of topics and lessons plans). 20 years after the publication of Deborah Pomeroy's seminal work on MSE in 1994, different authors (Krugly-Smolska, 2013; Allchin, 2014; Sarukkai, 2014; Ideland, 2018; Lee, 2018) are still drawing attention to the lack of empirical research about the use of this specific view of HOS in science lessons. Here, the main obstacle seems to be the need for a careful approximation between the view of modern science as intercultural and dynamic and reflections about its nature (NOS) in the field of Science Education.

In this context, some understandings of NOS appear to be more useful to this strategy, since they allow a less fixed and more open standpoint of what it is(are) in fact the nature(s) of scientific work. Here, a more holistic perspective about what NOS is [such as some views discussed by Driver and others (1996), Allchin (2011), and Erduran and Dagher (2014)], and a more contextualised approach adopted in NOS lessons may be reasonable if we aim to bring different contributions and relationships involved in the production of scientific knowledge to school science.

That was the position adopted, for instance, by Lee and Kwok (2017) and Lee (2018) in their work on resources for teaching scientific content and NOS in different topics from the science curriculum in Hong Kong[29], one of the few empirical studies employing the intercultural model available in the literature. They chose this model of HOS to inform a contextualised and explicit teaching of NOS integrated to scientific content to students aged 17-18 and had positive results in relation to "students' rich, diversified and nuanced characterisation of science and technology" and to their interest in this type of teaching and learning approach (Lee & Kwok, 2017, p. 162).

In this scenario where the potential of the intercultural model of HOS to the teaching of NOS seems to be gaining recognition in the field of Science Education, the lack of empirical studies that investigate the affordances and hindrances of this approach to school science needs to be addressed. What I am defending here is the importance of elaborating different intercultural proposals based on real scenarios and accounts of scientific development, an approach that seems to offer different and important possibilities to the teaching about NOS from a more diverse (and more up-to-date) take on HOS and scientific work. Thus, this study aligns itself with this perspective about the introduction of HOS (and NOS) into school science and will investigate how the intercultural model of HOS can (or cannot) find its way into regular

[29] Such as ceramics, fermented food technologies, and inoculation against smallpox.

science lessons to stimulate wider reflections about the development of scientific knowledge, while still considering the constraints and realities of English urban secondary schools and curriculum.

2.3.4. Final comments: rationale for the study

As discussed throughout this chapter, teaching about NOS is among the most advocated ideas in contemporary school science and its close connection with areas such as scientific literacy and science, technology and society movements has impacted curricular reforms and the production of curricular resources around this idea. In the past decade different investigations (Krugly-Smolska, 2013; Allchin, 2014; Sarukkai, 2014; Ideland, 2018; Kelly, 2018) have shown, however, the lack of reflections about the specific views of science and its history that are informing this introduction of NOS into science curricula, materials and practices. Most proposals available in the field of Science Education focus on examples from historical and contemporary cases in Western science, such as Atomic models and Geocentrism in sixteenth century Europe, with less attention being paid to how other cultural and geographical contexts contributed to these narratives.

It is important to highlight that I am not arguing here that it is inherently wrong to use these more paradigmatic historical accounts to address specific topics or ideas by school science (when, of course, this choice is relevant to what is being done in the lesson). What I want to emphasise is that the absence of other narratives, other examples that can be used to introduce similar or even new perspectives about NOS into school science seems problematic not simply from a moral/social justice perspective, but also from the perspective of teaching about NOS. With historical accounts available for these activities being based on a very specific and narrow cultural and geographical context, important aspects involved in the production of scientific knowledge (such as collaboration, negotiation and adaptation of scientific knowledge, exploitation and power struggle around natural resources and knowledge, ethical, economic and political aspects of science) will remain underexplored and even absent from the images of science being promoted by these lessons (Barton, 2001; Erduran, 2014; Aragón-Méndez, Acevedo-Díaz & García-Carmona, 2018; Ideland, 2018).

In this context, my main aim with this study is to contribute to this debate about use of HOS in the introduction of NOS into science lessons by investigating the possibilities and limitations of the 'intercultural model of HOS' (Sarukkai, 2014; Lee & Kwok, 2017; Lee, 2018). Special attention will be placed on whether and how the use of diverse scientific contexts and histories can foster students' learning about NOS.

Therefore, I position myself within the Science Education field with the argument that studying about NOS also needs to include discussions about the origins and development of science, encompassing its intercultural roots, which are grounded on diverse exchanges between cultures and societies throughout our history, as recent trends in the field of HOS have been prolific in demonstrating (Roberts, 2009; Elshakry, 2010; Fan, 2012).

By advocating this intercultural model, I need to acknowledge, however, that incorporating culturally diverse examples into the curriculum alongside the teaching of regular content can be a very difficult task (Lee & Buxton, 2010). Few projects around cultural diversity in school science have been carried out outside exclusively non-mainstream contexts (such as First Nations schools), with the focus still being placed on very specific and often relativistic settings (e.g. Jegede & Aikenhead, 1999; Gondwe & Longnecker, 2015; S. Hansson, 2018). Therefore, this study inserts itself within this gap between the field of MSE and NOS teaching and learning by working closely with urban secondary schools in London/U.K. As I will further elaborate in chapters 3 and 4, I opted to conduct a classroom-based investigation around current school science practices regarding teaching and learning about NOS through HOS, and about the possibilities and limitations offered by the intercultural model of HOS to these practices.

Chapter 3: Research Design

This study focused on school science practices related to teaching about Nature of Science (NOS) through historical approaches. In this chapter, special attention will be dedicated to the construction of a research design that aimed at investigating these practices under a qualitative approach. Section 3.1 introduces my aims and research questions, while section 3.2 describes the two research phases carried out during this study. In section 3.3 I will then explore the main philosophical and methodological perspectives informing this investigation, along with a general examination of its values and ethical aspects, also delineating how these specific positions were connected with my research design.

3.1. Research focus: aims and research questions

As argued in chapter 2, there are many ways through which science teachers can employ HOS and discuss NOS in their lessons, and the effects of curricular documents and official assessment, teaching resources, teachers' views about science education, and students' interests cannot be ignored in this scenario. This study about the possibilities and hindrances offered by a specific approach to the use of HOS (the intercultural model) in teaching and learning about NOS was then developed around two main aims:

- To investigate if and how teaching and learning about NOS is being incorporated into secondary science lessons, and if and what types of historical narratives are being employed in this process.
- To investigate if and how the intercultural model of HOS can aid teachers in teaching about NOS in secondary school science, including an analysis of the affordances for and hindrances of this model to the realities of these lessons and participants.

Some more specific objectives behind this investigation can also be outlined:

- To observe science lessons in key stages 3 and 4 in two urban schools in London/U.K. to investigate teachers' practices (e.g. examples, pedagogical strategies) regarding NOS and HOS.
- To investigate students' previous knowledge about NOS and about scientific development in different places.

- Taking into consideration the results generated through the investigation of the two previous objectives, to develop and implement a set of teaching and learning plans (TLPs) dedicated to the teaching about NOS through the intercultural model of HOS.
- To reflect about the process of developing these TLPs through collaborative work between one participant teacher and researcher.
- To investigate the impact of these TLPs on students' understandings about NOS and HOS.
- To reflect about the general potentialities and limitations of the use of the intercultural model of HOS to the teaching and learning about NOS and regular science content.

In order to achieve these main and specific aims, this investigation endeavoured to answer the following research questions (RQs):

RQ1. What are the possibilities and obstacles found in teachers' practices and realities for the inclusion of intercultural aspects of science into school science?

RQ2. In which ways are participant students aware of the history of scientific development carried out by different people in different places of the world? What can be influencing and shaping their awareness?

RQ3. What are participant students' main understandings about NOS? What can be influencing and shaping these understandings?

RQ4. In which ways can an intercultural model of HOS be successfully integrated into school science through TLPs to foster teaching and learning of NOS?

A research strategy was built to answer these RQs based not only on the main aims delineated above, but also on my views and position as a researcher in the field of (Science) Education. The following section includes an overview of this position, making the case for adopting a qualitative perspective for designing and implementing this study.

3.2. Summarising the two research phases: Exploratory and Implementation

My main interest with this research project was to investigate the use of the intercultural model of HOS to promote the introduction of NOS into regular secondary science lessons through the development of teaching and learning plans (TLPs) (RQ4). To inform the examination of the possibilities and obstacles offered by this model to school science practices, I opted to first look into the current scenario of teaching and learning about NOS and uses of HOS, followed by a reflection on the local and structural explanations for these realities (RQs 1, 2 and 3).

The choice of starting with an exploratory investigation of these realities was connected to some previously mentioned and well-known obstacles to the introduction of (innovative) ideas and practices into schools (Höttecke & Silva, 2011; Ryder & Banner, 2013; Henke & Höttecke, 2015). As argued by these authors, 'top-down' and context-independent proposals that do not take into consideration schools' culture and teachers' perspectives about (science) education tend to encounter resistance not only during the lessons, but also from more structural aspects, such as specific curricular aims and schools' approaches to examinations.

Trying to reduce the impact of these obstacles on the development and implementation of the TLPs, the first year of this project (known as 'Exploratory phase') aimed at understanding relevant aspects of the participant schools', teachers' and students' views on: teaching and learning science and about NOS, use of HOS, examinations, curricular aims, educational innovations, students' engagement and cultural diversity in science. It consisted of observing different science lessons (two schools; five science teachers; nine classes from years 8-10[30]; different ability groups[31]; topics in Biology, Chemistry and Physics) throughout one school year, paying attention to the way science teachers work alongside intercultural perspectives, NOS and HOS in their lessons (RQ1), coupled with interviews with them about their practices and realities. Furthermore, participant students' knowledge about HOS and diversity in science (RQ2) and about NOS (RQ3), and possible connections between their knowledge and school science practices were also investigated through the use of questionnaires, follow-up interviews and linked to lesson observations. The aim of this phase was then to generate an understanding about the realities of school science

[30] Students aged 12-15.

[31] Understood here as groups ('sets') of students organised by the participant schools according to their academic achievement (performance) in school work.

regarding my topics of interest, by both describing and building explanations for these scenarios.

The second year of this project (known as 'Implementation phase') involved the development and implementation of TLPs grounded on the intercultural model of HOS (RQ4). This experience was partially informed by the findings from the Exploratory phase, especially in relation to students' knowledge about NOS and HOS and to practices that seem to promote and those that seem to hinder knowledge development about NOS and diversity in science. This phase was carried out throughout one school year and it was analysed from different angles ('levels of analysis') drawing on scholarship from HOS, curriculum, pedagogy, teacher's and students' perspectives. Through a collaboration with one specific science teacher from my Exploratory phase we produced different TLPs to be taught to his year 8[32] class, following the regular science curriculum adopted by the school, and taking into account the official content expected for these lessons. This phase was then concerned with promoting changes in school science practices while also evaluating the constraints and possibilities, at the curricular, pedagogical and students' levels, of the resources developed.

3.3. Positioning this study in the field of Educational Research

3.3.1. Qualitative Research and Critical Realism

The choice of carrying out two phases (Exploratory and Implementation) of classroom-based research, characterised by descriptions and reflections about the investigated experiences, resulted in the adoption of a qualitative approach to this study. Since qualitative research has a general focus on investigating meanings and explanations for specific contexts and/or experiences (Denzin & Lincoln, 2003), this seemed a natural methodological option for a study that involved RQs based on a mix of descriptions ('what is happening?' – e.g. science teaching about NOS and use of HOS), explanations ('why is this happening?') and generalisations/contextualisations (going beyond a particular setting and looking for more structural and large-scale explanations) (Usher, 1996).

Designing a research process, however, involves more than adopting one specific inquiry approach. As argued by Denzin & Lincoln (2003) and Creswell (2013), there are different research traditions within a qualitative approach[33], and they will differ in their ontological (how we understand the nature of reality), epistemological (how we

[32] Students aged 12-13.

[33] Such as Positivism, Critical Realism, Critical Theory, (Socio-)Constructivism, and Cultural Studies.

understand the nature of knowledge production about this reality), and axiological (how we recognize our values as researchers influencing our work) positions. These differences will affect not only more instrumental steps of the research (e.g. methods of data generation), but also how the data analysis and the writing about these findings will be done (e.g. aspects of the data that will be explored), and how these will be interpreted and understood in terms of validity and generalisation.

Within this project, my understanding of the 'reality' of school practices and students' knowledge related to NOS and HOS went beyond what can be actually observed in science lessons and seen in answers to questionnaires or heard in interviews about these topics. Thus, I was not interested in simply investigating what was happening at the participant settings during both research phases and developing one unique level of analysis/explanation (e.g. teachers' practices, or teachers' perspectives, or students' perspectives) for these findings. Instead, my aim at both phases was to understand the interplay between these different levels of analysis behind the 'reality' of specific choices teachers make when teaching (or not) about NOS and using HOS and behind their students' knowledge about these topics (Gorski, 2013).

The ontological position assumed in this investigation was then of approaching the reality of the problem as 'layered': the result of the interplay between different dimensions that would influence what is observed in the lessons and grasped from participants' views about NOS and HOS. Therefore, some ideas from the Critical Realist (CR) perspective inspired this study due to its specific view of the 'reality' of the social world as stratified.

In a nut shell, taking an ontological position within a CR perspective entails exactly the recognition of a social reality (such as a set of teaching practices or students' knowledge about NOS and HOS) as multi-layered, that is, as the result of interactions between distinct 'objects' within a larger system (for instance, teachers, students, curricula and curricular materials, and scholarship of the field of HOS) (Bhaskar, 2008; 2017). According to Gorski (2013, p. 667), within a CR perspective:

> We begin by analyzing the world into discrete structures, such as 'human persons' or 'social networks'. We proceed by thinking through how interactions between these structures lead to changes in their properties or relationships or even to the emergence of new structures. We then reflect on the temporal and spatial and cultural scope of these interactions as part of a system.

This layered approach to a research problem recognises the importance of looking at it from different perspectives, while also trying to connect these perspectives, finding out more about the mechanisms (‘causes’) behind this investigated scenario. According to Given (2008), CR has then a strong focus on developing multi-layered explanations for the realities being investigated, starting from the study of an event (descriptions and search for patterns) and then moving onto its causes (‘retroduction’ process). In addition, some authors (Given, 2008; Scott, 2010; Gorski, 2013) argue that by also concentrating on the understanding of the different possible ‘causes’ behind an event, CR can overcome some of the criticisms faced by relativist traditions, such as Constructivism, which tend to focus solely on individual interactions (hence the relativist aspects), not taking into account larger social structures involved in the phenomenon:

> [C]omplete explanations of social events and processes cannot be reduced to the intentions of agents without reference to structural properties or to structural forms without reference to the intentions and beliefs of agents. Methodologically, this implies that any investigation can only take place at the intersection or vertex of agential and structural objects, and thus indicators that researchers use have to reflect this close relationship between the two (Scott, 2010, p. 34).

CR then acted as an inspiration for the design of both research phases because it entails a movement beyond simply describing school practices related to NOS and HOS[34], looking at them from one or two specific perspectives (e.g. teachers' perspectives or science curricula). Instead, it explores the interplay between individual (‘agential’) and structural aspects behind these investigated realities. The creation of a tentative understanding of these school practices during the Exploratory and Implementation phases was guided by the interconnection between teachers' actual practices, teachers' and their students' views of these practices and of NOS, HOS and science education, and curricular and assessment scenarios, including agential (e.g. teachers' personal and professional epistemologies and students' interest in science lessons, HOS and NOS) and structural (e.g. science curricula, official examinations, curricular resources, and scholarship of the field of HOS) aspects.

My choice of understanding this investigated reality as multi-layered and influenced by agential and structural aspects can also be connected with the planning and development of the Implementation phase (RQ4). As argued by CR researchers, by better understanding the multi-layered reality of a context, social research can facilitate the planning and implementation of change in different settings (Scott, 2010; Gorski, 2013; Fletcher, 2017). Therefore, adopting a perspective inspired by CR in the

[34] Named as the ‘empirical level’ in the CR framework, that is, the world that is ‘experienced’.

Exploratory phase had the potential to uncover agential and structural aspects that could impact the process of integrating the intercultural model of HOS into teaching practices.

3.3.2. Knowledge production and validity

The adoption of this multi-layered perspective also impacted my approach to how the knowledge produced throughout this study was going to be understood (my 'epistemological position'). By considering the researched context as a product of the interplay between different agential and structural aspects, the knowledge I was able to generate about the reality of school practices was inherently multi-layered (i.e. including different perspectives, participants and levels of analysis) and grounded on my and participants' interpretations of how these agential and structural aspects were connected.

My position within this study was then that the knowledge produced was of an 'interpretive nature' (Dey, 199, p. 3; Elliott & Timulak, 2005), "orientated to providing thorough descriptions and [tentative] interpretations of social phenomena, including its meanings to those who experience it". By using a descriptive-interpretive approach, I had no official pre-developed categories to analyse the data generated besides specific sensitising topics that I wanted to explore (e.g. how teachers talk about NOS, whether and how they use HOS), and the findings from each phase were described and then interpreted in connection with agential and structural particularities of the settings (e.g. teachers' and students' views, curriculum).

This interpretive nature of my work is connected with a perspective known as 'epistemological relativity', which understands knowledge as being socially-constructed during the research process and bounded to the contexts (historical, cultural, political) where the research is carried out (in my case, participant schools following specific schemes of work in London/U.K.). Nevertheless, in this scenario of a context-bounded knowledge and multi-layered social reality, "human knowledge captures only a small part of a deeper and vaster reality" (Fletcher, 2017, p. 182); that is, social practices can be influenced by different and not necessarily easy to be accessed factors such as (un)known conditions, tacit skills, and (un)conscious motivation (Benton & Craib, 2001; Scott, 2010), bringing an analytical challenge to my study.

Understandably, this interpretive and relativist view of knowledge construction has received some criticism (Denzin & Lincoln, 2003; Bhaskar, 2017), especially in relation to the question of validity of its interpretations: "[a]re these findings sufficiently authentic (isomorphic to some reality, trustworthy, related to the way others construct their social worlds) that I may trust myself in acting on their implications?" (Lincoln &

Guba, 2003, p. 274). Critics of an interpretive/relativist approach are concerned with the possibility that if knowledge is relative, fallible and provisional we might not have any criteria to assess the validity of the claims being made by a study, opening the possibility for any kind of knowledge statement to be accepted as valid and trustworthy (Denzin & Lincoln, 2003). In this scenario, when doing research under an epistemological position of interpretive nature, is it possible to be “interpretatively rigorous” (Lincoln & Guba, 2003, p. 275)?

While this study was aligned with a view of knowledge as socially-constructed, dynamic and fallible, I was also concerned with how my research design and data analysis would address this issue of validity. I wanted to ensure that my findings and interpretations about the Exploratory phase would be (as much as possible) close to the realities being investigated to inform the development of the Implementation phase. Furthermore, since my main interest here was to investigate the possibilities offered by a new historical approach to NOS teaching, a trustworthy analysis of this experience would enable me to reflect on the different ways innovative school science practices can be promoted in other contexts and possibly scaled up.

The issue of being ‘interpretatively rigorous’ was tentatively addressed in this study with the help of specific perspectives put forward by the CR tradition, where validity is discussed in relation to its position as an ontologically realist and epistemologically relativist paradigm (Yucel, 2018). CR then aligns itself with the idea that absolute knowledge about the ‘real’, about what exists (the ‘intransitive dimension’) is impossible and explanations about the world are always incomplete and open to critique (‘transitive’). Hence, according to Scott (2010) and Fletcher (2017), CR recognises the importance of subjectivity and socio-cultural influences to knowledge production, as Constructivist and Cultural Studies traditions.

Nevertheless, CR differentiates itself from these other epistemologically relativist traditions exactly by addressing the question of validity and rigor of interpretations (Yucel, 2018). In his works on this topic, Bhaskar (2017) advocates the adoption of ‘judgemental rationality’ to address the issue of making valid judgements about the different interpretations in social research. He argues that “even though our knowledge is relative, we can produce in particular contexts, strong arguments for preferring one set of beliefs, one set of theories about the world to another” (Bhaskar, 2017, p. 20).

According to Scott (2010), an approach employing ‘judgemental rationality’, while still considering knowledge relative and incomplete, will involve a constant reflection about how the explanations produced connect with other (previous and current) ways of analysing the subject (a process known as ‘theoretical redescription’ or ‘abduction’). Furthermore, the very adoption of a multi-layered ontological perspective towards the subject (reality) being investigated will impact the trustworthiness of the research since it promotes the consideration of different voices and dimensions in the process of knowledge construction (Scott, 2010; Fletcher, 2017; Yucel, 2018). Therefore, a constant interplay between employing different perspectives (e.g. from teachers, students, curriculum, researcher) on the research problem and conversations with other bodies of research produced around similar topics should help generating interpretations through a more rigorous process.

While there are very few works in the literature clearly describing ways of using ‘judgemental rationality’ in social research, as argued by Robert Isaksen (2016) and Fletcher (2017), I attempted to carry out this process through two main interconnected pathways. First, the adoption of a ‘judgemental rationality’ strategy can be seen in my choice of using a multi-layered approach to the presence of NOS and HOS in school science, gathering data from different participants, considering different levels of analysis, and cross-checking my own interpretations with participants’ views and own explanations.

Nevertheless, my aim here was not to use this multi-layered approach to simply formulate a ‘thick description’ (Bhaskar, 2017) of schools’ realities, but to connect my ‘setting-specific’ interpretations with a broader body of research coming from other contexts. The process of ‘theoretical redescription’ was then used to position my findings and interpretations within (science) educational research through a constant engagement with different literature in the field (Scott, 2010; Robert Isaksen, 2016), focusing on: teaching and learning about NOS; uses of HOS in school science; representativeness in school science; curriculum and assessment constraints in school practices; teachers’ professional development; resources development; among others.

In summary, I employed the practice of ‘judgmental rationality’ in the form of a multi-layered approach both to the research design and to the interpretations constructed, and through the constant search for agential and structural aspects involved in the investigated realities (‘retroduction’) that could consequently be confronted with other similar research in the fields of Education, NOS and HOS (‘theoretical redescription’). My purpose was then to look for a certain level of authenticity and validity to my interpretations about participants’ realities of school science not only by considering different voices and perspectives, but also by positioning these experiences in relation to other contexts and research developed around similar topics.

More detailed accounts about how this process was carried out will be given in the next chapter 4, which will deal with the specific methodological choices made in each research phase, and in chapters 5, 6 and 7, which will present the main findings and interpretations generated throughout this study.

3.3.3. Final comments: some reflexive thoughts and ethical aspects

According to Lincoln and Guba (2003), any research design in the field of Social Sciences[35] will be impacted by the researcher's values, which will in turn influence decision-making processes throughout the investigation. Furthermore, placing this study specifically in the sphere of an interpretive perspective means that it cannot be seen as 'value-neutral' (Gorski, 2013), since the knowledge generated was influenced by my own relationships with and views about Science Education. Therefore, I need to acknowledge here the values, social and political roots of this project that are connected with my own professional positioning not only as a researcher in the field, but also as a science teacher.

One important value informing this study was my commitment to collaborative work with a science teacher to promote change in school science practices. This choice was not solely inspired by findings from educational research about the general inefficiency of top-down approaches (Höttecke & Silva, 2011; Ryder & Banner, 2013; Henke & Höttecke, 2015), as already mentioned here. As a science teacher myself, this interest in developing the Implementation phase based on a collaboration was also connected with the appreciation and recognition of teachers' professional expertise, that is, with the acknowledgement that their own experience would be of utmost importance to the planning and developing of the TLPs.

Furthermore, my "choice of research problem" (Lincoln & Guba, 2003, p. 265) – that is, of working with an intercultural approach to HOS – was also aligned with my professional views about educational research and science teaching and learning. In this case, not only my commitment with a decolonial view of HOS informed this study, but also my critical view of science education, grounded on my training and practice as a science teacher in Brazil, with an input from Paulo Freire's works on Critical Pedagogy.

My "choice of context" (Lincoln & Guba, 2003, p. 265) for this study – that is, of comprehensive schools – was also influenced by my view on the importance of access to a good, free and empowering educational system as a means of social justice, and by my former experience as a science teacher in the same type of school. Investigating this context can be then understood as a consequence of my interest in reflecting about my own professional affiliation. Similarly, my "choice of major data-gathering and data-analytic methods" (Lincoln & Guba, 2003, p. 265) was also impacted by this former teaching experience: considering the different actors (e.g. teacher, students,

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[35] And, according to non-positivist perspectives, also in the field of Natural Sciences (Walsh, 1999; Bhaskar, 2008).

school) and structures (e.g. curriculum, assessment, and many others) behind school science practices was a natural choice of research strategy in the light of my previous experience with the complexities of this reality.

Therefore, it is important to emphasise here, once again, that the decisions made throughout this research and, consequently, the knowledge produced from it cannot be considered value-free or neutral, since they were informed by my commitments with a specific view of (Science) Education. As a result, and in accordance with the ontological and epistemological positions assumed here, data generated throughout this investigation are understood as evidence for an inferential process of analysis that aimed at finding indicators for the existence of patterns and mechanisms behind the investigated practices. These findings and analysis are then subjective and theory-laden in nature but constructed through rigorous interpretive process with the help of a 'judgmental rationality' strategy.

Another important aspect involved in this research is the reflection about ethical issues that naturally arise from any study involving human beings (Scott, 1996; Christensen & Prout, 2002). One of the main ethical aspects interweaved with this study was my aim to not only describe and analyse school practices, but also to work alongside the participants to reflect upon their realities. This methodological choice was then both connected with strategies behind the implementation of innovative practices and with my position as a former science teacher, as argued above, and with an ethical commitment to giving voice and opportunity for reflection to the participants (Scott, 1996; Christensen & Prout, 2002).

Considering these 'fieldwork' responsibilities towards the participants (Scott, 1996), this study also adopted other strategies regarding possible ethical issues. First, informed consent was obtained from parents/carers, students and teachers, in accordance to BERA Ethical Guidelines (BERA, 2011). They were asked about their consent through written forms (opt out model for students and their parents/carers, opt in for teachers) for each research phase, and constantly reminded during all stages that they could withdraw their consent and avoid answering specific questions at any time.

Second, as argued by Christensen and Prout (2002) and Scott (1996), school-based research demands specific ethical deliberations, where the choice of methods, approaches and negotiations between researcher and school are constructed continuously during the investigation. In relation to my presence in the school, care was taken while approaching science teachers and students, with a four-month period dedicated to building rapport prior to the start of the Exploratory phase and before any official data generation (Punch, 2002). The initial months of my empirical investigation were then employed to get to know teachers and their students, making myself present in their science lessons and staff meetings to diminish the possibility of embarrassment by having a ‘strange person’ around the school and the lessons, and to familiarize students with a ‘second pair of eyes’ in their environment (Tilstone, 1998).

More details about these strategies will be explored in the following chapter 4, which will focus on the sampling processes, and methods for data generation and analysis specifically employed in each research phase.

Chapter 4: Research Methodology

In the following sections, the settings, sampling, and methods of data generation and analysis adopted throughout this study will be presented. Whilst being both of a qualitative nature and complementary to each other, the Exploratory and Implementation phases also entailed some distinct methodological choices and procedures that will be described in this chapter.

4.1. The Exploratory phase – methodological strategy

The Exploratory phase, as mentioned in the previous chapter, aimed at investigating if and how teaching and learning about NOS has been incorporated into secondary science lessons, and if and what types of historical narratives have been employed in this process, focusing on the following three RQs:

RQ1. What are the possibilities and obstacles found in teachers' practices and realities for the inclusion of intercultural aspects of science into school science?

RQ2. In which ways are participant students aware of the history of scientific development carried out by different people in different places of the world? What can be influencing and shaping their awareness?

RQ3. What are participant students' main understandings about NOS? What can be influencing and shaping these understandings?

It is important to highlight that my aim with this phase was not to simply pilot research instruments (such as interview schedules or questionnaires) but, more importantly, to 'explore' school science realities and possibilities in relation to relevant topics to the Implementation phase, such as HOS, NOS, diversity in science lessons. The value of this Exploratory phase was then to reduce the possible obstacles to the implementation of innovative practices that usually arise from 'top-down' and context-independent proposals that do not take into consideration teachers' and students' own realities and perspectives (Höttecke & Silva, 2011; Ryder & Banner, 2013; Henke & Höttecke, 2015).

Due to my goal of producing an in-depth and multi-layered analysis of school science practices, I opted to carry out this phase during one school year at two secondary schools in London/U.K., based on Case Study strategies (Yin, 2003; Stake, 2005; Taber, 2013). A case study is an approach that “investigates a contemporary phenomenon within a real-life context” (Yin, 2003, p. 13), and it is often preferred when questions like ‘how?’ and ‘why?’ are posed about a specific phenomenon (the ‘case’ being studied), such as the RQs proposed for this research phase. Based on that, adopting a case study strategy to ground this investigation seemed adequate, especially due to my interest in describing and subsequently interpreting school science practices at the two participant schools over a long period of time (Stake, 2005).

Even though Roy Bhaskar’s original writings did not recommend any specific methodological strategy to be employed when adopting a Critical Realist approach, several CR researchers (Dobson, 2001; Mingers, 2004; Ackroyd, 2010; Easton; 2010) have argued for the compatibility between CR and Case Studies. According to Wynn and Williams (2012, p. 795), the aims of case study strategies, such as the ‘how?’ and ‘why?’ questions and the in-depth analysis of the phenomenon (or ‘reality’) under study, are coherent with the investigation of “the interaction of structure, events, actions, and context to identify and explicate causal mechanisms”, the main characteristic of a CR approach.

Additionally, a CR perspective can, at least partially, help case studies out of the epistemological relativism traditionally related to this approach by the adoption of ‘judgemental rationality’ (Easton, 2010). Employing some aspects from ‘judgmental rationality’ discussed in the previous chapter, such as a multi-layered understanding of the case and the development of explanations encompassing both contextual and structural aspects, can offer case studies a pathway to respond to usual criticisms regarding the ‘transposition’ of its context-based knowledge (‘case-based knowledge’) to other contexts (Easton, 2010; Scott, 2010). In this scenario, I aimed at connecting findings about my cases with structural aspects that could be influencing these realities (‘retroduction’) and with other experiences, cases and educational theories and perspectives (‘theoretical redescription’).

Each case under study within this project can be characterized as ‘instrumental’[36]: they were two typical urban secondary schools in London/U.K. selected through convenience sampling – that is, not because they were very particular contexts, but because they were willing to participate. The option to work with two cases studies in this phase aimed at improving knowledge about a wider phenomenon of school science practices that could go beyond the contexts of these two specific settings (Taber, 2000). In addition, each participant class and each participant science

[36] A case that is a means to understand and represent a more general phenomenon or reality (Stake, 2005).

teacher can also be considered sub-cases within each school due to their particular natures (division in different years/abilities groups, for instance). In the following sub-section, the selection process and characteristics of these two participant schools and their sub-set of participant science teachers and their classes will be described.

4.1.1. Settings and Sampling

This investigation was carried out at two secondary comprehensive schools in London/U.K., where my research institution is based, during the school year of 2016/2017. This level of schooling was chosen due to my previous experience as secondary science teacher in Brazil, which would put me in a more familiar position in relation to curricular and pedagogical strategies. In addition, secondary school science has a historical connection with HOS and NOS teaching in England (Taylor & Hunt, 2014), so I was expecting to find at least some practices related to HOS and NOS in the participant classes.

The sampling process started by contacting schools in London through the PGCE Science programme at my institution and included an approach letter explaining my research proposal and enquiring about their interest in participating. After these contacts, two schools (schools A and B) agreed to receive me for informal observations of their science lessons and for further talks about my project, and a subsequent official agreement for the development of this Exploratory phase was reached with both settings.

School A is an outstanding[37], non-faith and mixed-sex school, specialising in STEM subjects; school B is an outstanding catholic school for girls. Both have at least 50% of students with English as a second language. Schools A and B have, respectively, around 860 and 900 students enrolled in their key stage 3 (KS3) and key stage 4 (KS4) cycles. School A follows the KS3 curriculum in years 7 (11-12 year olds) and 8 (12-13 year olds) and the KS4 curriculum in years 9 (13-14 year olds), 10 (14-15 year olds) and 11 (15-16 year olds). Meanwhile, in school B, years 7, 8 and 9 study the KS3 curriculum, and years 10 and 11 follow the KS4 curriculum.

The sampling process (convenience sampling) within each school started with the year group: years 8, 9 and 10 were selected as potential participants to ensure a mix between two different curriculum cycles (KS3 and KS4). Other years that are also

[37] According to OFSTED (Office for Standards in Education, Children's Services and Skills), the English office responsible for inspecting and regulating services provided by educational institutions. An 'outstanding' rating is the highest in the current grading scale adopted by this office.

part of these cycles were excluded due to students' young age[38] and concerns about official assessments[39]. Among all year 8, 9 and 10 classes at the schools, a total of nine were chosen for this study, a selection process based on three main criteria: teachers' willingness to engage with this research, their views about NOS and diversity in school science, and their timetables during the year of the Exploratory phase. The willingness criterion was mainly important at school B, where only two teachers from the Science Department responded to my initial invitation. In this case, their views about NOS and diversity in school science were not employed as a criterion for their selection, since they were the only ones available at this school.

At school A five teachers answered my invitation, so a second selection process was adopted, using their views about science education (teaching about NOS and diversity in science) investigated through preliminary interviews (see appendix 1) as a criterion. Four teachers were then selected after saying they had tried to discuss NOS in their lessons before. This choice was made due to my interest in observing science teachers' lessons under the particular lenses of intercultural aspects of science and teaching about NOS, and not as a general investigation of different types of regular teaching practices. Therefore, to generate relevant data for this research participant teachers had to, at least in theory, be mindful of, and interested in, NOS and intercultural perspectives about science.

Lastly, a third criterion was also employed to select only three teachers among the four singled out at school A after the preliminary interviews: their timetables in the following school year. The final group consisted of three teachers who would be teaching different subjects (Biology, Chemistry and Physics) to different ability groups (mixed, sets 1, 2 and 3) of years 8, 9 and 10. By using this criterion, I was able to build a heterogeneous set of classes to work with; that, coupled with my work at school B, allowed me to rely on diverse contexts and experiences to answer my RQs.

Although the selection of participants in both schools aimed at producing a heterogeneous sample, my work only with teachers sympathetic to my research topics impacts the extent to which this group can be considered in fact heterogeneous. Leaving behind teachers who claimed to not take NOS or intercultural perspectives into account in their teaching diminished my chances of observing implicit practices. In this scenario, I must acknowledge a possible source of bias regarding the data generated by this study: my time constraint as a sole researcher was an obstacle to the work with a larger group of teachers.

[38] In the case of year 7 students, who were new to the secondary school setting and could feel overwhelmed by the novelty of having to answer different questionnaires and engaging with interviews.

[39] In the case of year 11 students, who were at their last year of secondary school and focused on official examinations.

The final set of participants consisted of 200 students (58.5% girls, 41.5% boys) from years 8, 9 and 10 and nine different classes. The distribution of participant students and their demographic information[40] can be found in appendix 3. Five science teachers were responsible for the science lessons in these nine classes and considered as participants as well (see appendix 4 for their demographic information).

4.1.2. Data generation and analysis

As summarised by table 2 below, this research phase involved different methods of data generation, such as lesson observations, interviews, open-ended questionnaires and focus groups. This adoption of a multi-method approach was connected with the use of case studies (Yin, 2003; Stake, 2005) and classroom-based research (Erickson, 2012; Taber, 2013), which often employ a considerable number of sources of information to understand the realities under study.

The process of data analysis was based on a qualitative tradition of coding through an inductive strategy: an interactive and generative process of looking at the data and trying to find important commonalities, differences and relationships between the initial findings, while avoiding the use of pre-conceived categories to be applied upon participants, contexts and actions (Flick, 2011). Data analysis then involved a process of coding the initial instruments of data generation for each RQ (observation sessions or questionnaires) to find patterns and dissonances to be further explored in follow-up interviews with participants.

[40] This self-declaration was collected through a set of questions (see appendix 2) part of the HOS questionnaire, to be further discussed in this chapter, and that were based on the literature from the field of Cultural Studies.

Table 2. Outline of the methods of data generation and analysis – Exploratory phase

	Exploratory phase		
Proposed methodology	*Research question 1* What are the possibilities and obstacles found in teachers' practices and realities for the inclusion of intercultural aspects of science into school science?	*Research question 2* In which ways are participant students aware of the history of scientific development carried out by different people in different places of the world? What can be influencing and shaping their awareness?	*Research question 3* What are participant students' main understandings about NOS? What can be influencing and shaping these understandings?
Method(s)	- Lesson observations - Follow-up interviews with participant teachers and students	- HOS Questionnaire with students (open-ended, including demographic questions) - Post-questionnaire follow-up interviews with participant students and teachers - Lesson observations	- NOS Questionnaire with students (open-ended) - Post-questionnaire follow-up interviews with participant students and teachers - Lesson observations
Analysis	Qualitative data analysis (coding + connection between field notes, audio-recorded lessons and interviews)	Qualitative and quantitative data analysis (coding + connection between questionnaires, interviews and observations)	Qualitative and quantitative data analysis (coding + connection between questionnaires, interviews and observations)

Answering RQ1 - Observations and interviews

One of my goals in the Exploratory phase was to explore science teachers' practices and realities regarding intercultural aspects of science, NOS and HOS. In order to investigate these practices, the method of participant observation (Tilstone, 1998; Wragg, 1999) of different science lessons was adopted. These observations were based on a previously developed and piloted guide[41] inspired by the fields of MSE, HOS and NOS.

From the field of MSE, Angela Barton's work (2000) on how the question of diversity can inform science teaching was especially useful to these lesson observations, focusing on three main areas: Disciplinary knowledge; Pedagogy; and Relationship between science, society and students. In a nutshell, 'Disciplinary knowledge' is linked to a social and cultural view of scientific knowledge, including its social uses and construction: "scientific knowledge is viewed as being constructed from social acts where the individual, who is at the same time a social being, interacts with society and culture in a distinctive way to create something" (Barton, 2000, p. 798-799). 'Pedagogy', in turn, is related to "pedagogical strategies that link ways of knowing brought to school by students such as caring, co-operation, holistic approaches and out-of-school activities even when those ways are not obviously part of science" (Barton, 2000, p. 799). Lastly, 'Relationship between science, society and students' is connected to the previous two strands and it is mainly concerned with aspects of scientific literacy and to which 'science' is being taught.

Works from the field of HOS and NOS, such as Hodson (1992; 2014a), Forato and colleagues (2012), Allchin (2014), Sarukkai (2014), also inspired my observations, focusing on: if and how intercultural perspectives (related or not to HOS) appear in science lessons; how science and scientific development are portrayed in science lessons; how NOS and HOS are incorporated into regular science lessons. An overview of the aspects observed can be summarised as:

• The examples the teacher is using in science lessons (ancient science, modern science, Western science, local science, out-of-school knowledge – whose knowledge is being taught?);
• How the teacher is using these examples;
• How students interact with these examples and discussions (out-of-school and/or specific cultural knowledge; narratives; debates; questioning);

[41] Two observation sessions of science lessons (one with an year 7 and another with an year 9 at school A) were carried out to pilot this guide before the official start of the Exploratory phase.

• Discussion about NOS (view of NOS portrayed – product versus process; social and cultural dimensions; social use of knowledge);
• Use of HOS (mediation between HOS and science teaching needs).

During one school year (2016/2017), 50 lessons (topics in Biology, Chemistry and Physics) were observed at schools A and B (see appendix 5 for details of the lessons observed). These were selected with the help of the participant teachers, also taking into account my research aims and some empirical experiences found in the literature on NOS teaching, HOS and MSE (Hodson, 1992; 2014a; Forato et al., 2012; Allchin, 2014; Sarukkai, 2014; among others). After informal conversations about NOS, HOS and intercultural perspectives, the teachers mentioned the topics they felt to be closely connected with these types of scenarios and discussions, such as Space, Stem Cells, and Magnetism.

The topics observed were limited by my available time to visit two different schools and nine different classes during one school year. Around two-three topics were observed in each class, lasting around three-four hours per topic. An effort was also made to enable variability and comparisons: same topics were observed in different ability groups with the same teacher (e.g. Endo/exothermic reactions in year 9 sets 1 and 3); same topics were observed with different teachers (e.g. Inheritance in year 8 at school A and at school B); different topics were observed in the same class with the same teacher (e.g. Space and Drugs in year 8 at school A); different topics were observed in the same class with different teachers (e.g. Biology and Chemistry in year 9 set 1 at school A).

Data generation during these sessions was informed by my field notes (a specific hand-written notebook was kept) and by an audio-recording device placed with the teacher during the lesson. This choice of placing the device with the teacher (and not with students) was done mainly due to the nature of my aims during these observations: since I was interested in teachers' practices and choices when planning and teaching their lessons, my focus at this stage of the research was on them. Nevertheless, interactions with their students (e.g. questioning and participation) were also observed and written in the form of field notes, complementing what was not possible to be recorded by the device.

After each lesson, I re-read my field notes and added to them brief comments in the form of bullet-points to summarise my main impressions and general connections between each specific lesson and my research aims (pre-analysis stage). I then listened to the audio-recorded files, and the main passages that could complement/illustrate my field notes (such as dialogues between teacher-student; questions/instructions from the teacher; lesson talk about an example) were transcribed verbatim. My choice of not transcribing the whole audio-recorded lesson was related to the unworkable amount of audio-data that would be generated after observing 50 lessons and to my interest in teachers' practices and not in perspectives from the field of Linguistics, such as Discourse Analysis.

All data generated during these observation sessions were analysed through an iterative process of thematic analysis using qualitative coding (Coffey & Atkinson, 1996; Charmaz, 2014). This process entailed a constant organisation and re-organisation of my data into different codes after each observation session, in which new data would feed into previously developed codes, altering them and/or adding depth to them, generating overarching themes. I then coded (incident-by-incident) any new observation session (lesson) through a comparative perspective, that is, every new item of data generated was separated, coded and compared to the codes developed for previous lessons (Coffey & Atkinson, 1996). Here my unit of analysis was each ‘incident’ that happened in a lesson and that was related to my research interests (e.g. teacher using HOS, student asking a question related to NOS, teacher using one specific example).

Although I had a list of sensitising topics that I wanted to explore in relation to HOS and NOS teaching (in the form of my observation guide), this process can be considered of mostly inductive nature, that is, with the codes and final themes arising from the data. Here I was not concerned with categorising teachers in some pre-conceived groups according to their practices (informed by other empirical or theoretical investigations), mainly because I was adopting a new (intercultural) approach to HOS and NOS. Thus, any pre-conceived set of categories, codes or theory would probably not be enough to inform the development of a complete analysis under only one specific social/educational theory or approach, hence my choice of developing codes for the data from scratch (Coffey & Atkinson, 1996). This work was then of a thematic analysis nature, also inspired by Grounded Theory methodological strategies for inductive coding (Charmaz, 2014), though it is worth noting that generating a new ‘theory’ about these practices was not the aim of this research.

New observation sessions, constant analysis and comparisons between relevant ‘incidents’ and codes helped me to collapse, discard and further develop these initial codes (which were mainly indicators/descriptors of what was happening in the lessons) into four more robust/focused themes[42], with more meaning and analytical strength in relation to my research aims. In chapter 5 (containing the findings and analysis of this Exploratory phase), these final themes will be defined, illustrated and analysed.

[42] ‘Drawing on examples’; ‘Interacting with students' knowledge and interests’; ‘Connecting knowledge with socio-scientific contexts and people's lives’; ‘Talking about science and its nature’.

Even though the method of observation is intended to describe the realities of a set of lessons, ‘talking to informants’ is also important in school-based research (Delamont, 2002). According to Wragg (1999), indirect methods such as interviews can provide further information on motives, attitudes, values and beliefs, being useful to an exploratory small-scale case study like the one described here. Tilstone (1998) also highlights that, in the case of partnership observation (when an outsider observes the practice of an insider within a specific class, for instance), the process of discussing the findings from the sessions and of reflecting on what has been learnt can also be relevant to the practitioner’s (teacher) professional development.

Therefore, RQ1 was also addressed by interviewing the teachers involved in these lessons, aiming not only at cross-checking my field notes with them, but also at deepening my understanding of their realities. These interviews were semi-structured and based on the themes from my observation sessions, on teachers’ impressions about the curriculum and their students, and on ideas related to NOS and HOS[43]. These interviews were carried out at the end of the school year (after school hours or during the teachers’ non-teaching time) and were audio-recorded.

The analysis of these interviews was informed by an interpretative approach (Dey, 1993; Elliott & Timulak, 2005) to understand how teachers were giving meaning and explanations for their practices. The choice of an interpretive approach to guide my analysis was then related to the aim of not only describing teachers’ practices through the constructed themes, but also of developing a critical understanding about them within these teachers' realities (Denzin & Lincoln, 2003). Nevertheless, as argued in chapter 3, while an interpretive procedure can reveal meanings and develop explanations for the data generated, its adherence to an epistemologically relativist position can impact the validity of the claims made (knowledge generated) by the researcher. In other words, while the aim of producing explanations about the realities being studied certainly moves the qualitative analysis beyond a simply descriptive coding process, how did I attempt to be rigorous about these interpretations?

The CR perspective discussed in chapter 3 then informed this stage by moving my work around these interpretations forward to the development of a multi-layered analysis of my observations and interviews. They were interpreted with the help of the participants, exploring different possible agential and structural aspects behind these practices (a ‘retroduction’ process that moves from the description of incidents to the study of its causes), such as science curriculum, curricular resources, students’ interests and teachers’ views of science education. It was my aim to promote the consideration of different voices and dimensions on the knowledge construction about these teaching practices (Scott, 2010; Fletcher, 2017), while also connecting these

[43] See appendix 6 for the interview schedule (teachers).

ideas with discussions found in the field of Science Education ('theoretical redescription'), as it will be seen in chapter 5.

Answering RQ2 – HOS questionnaire, interviews and observations

The initial instrument used for the investigation of RQ2 consisted of an open-ended questionnaire about HOS applied to all participant students, which aimed at gathering an overview of their knowledge about people and places involved with science. This instrument was employed to elicit main topics and trends related to RQ2, and to inform a more detailed discussion about its results during my follow-up interviews with these participants. Since the goal of this instrument was to explore students' ideas about people and places involved in science, a decision was made to have it as an open-ended questionnaire instead of using forced-choice items, which would mean providing them with specific options, diminishing students' original contributions to the responses (Driver et al., 1996).

The questions employed were an adapted version of the instrument developed by Gurgel and colleagues (2014) in their study about Brazilian students' views on who participates in scientific research[44]. Some changes were made to adapt the original instrument to a non-country-specific format. Extra questions were also added to get a deeper understanding of their knowledge about these people and places. The final questionnaire can be seen below:

Q1. During your lessons you may have heard of many scientists who contributed to the development of science. Please, name some of them.
Q2. Do you know where these scientists were born?
Q3. Do you know what these scientists' studied, developed or did in science?
Q4. Which countries do most to contribute to the development of science nowadays?
Q5. Which countries/civilizations did most to contribute to the development of science in the past?
Q6. Besides those countries you named in questions 4 and 5, have you ever heard about scientific work developed in any other different place/country/civilization or maybe in a community with the same ethnic origin that you are?
Q7. If you said YES to the previous question, where did you hear about these scientists and contributions?

Since there was no information in the original article (Gurgel et al., 2014) about the process of validation of this questionnaire, and due to the modifications introduced by this study, I opted to carry out rounds of pilots of my adapted instrument. The first was done by applying it to two senior researchers in the field of Science Education,

[44] "(a) During your lessons you may have heard of many scientists who contributed to the development of science. Cite some of their names; (b) Do you know of any Brazilian scientist who made important contributions? Who?; (c) Cite the countries that most contribute to the development of science; (d) Do you believe that Brazil contributes to the scientific world? Why?" (Gurgel et al., 2014, p. 369).

who were also aware of the rationale of behind my study, to check for any inconsistencies both in the content of my questions and in the language use. Secondly, four rounds of pilot studies were carried out with groups of 4-5 students from years 8, 9 and 10 at school A: they worked on the questionnaire and a subsequent group discussion was carried out about any language misunderstandings (confusing sentences and unknown vocabulary) and general doubts about the questions being asked. Small modifications and clarifications in terms of language were then incorporated into the instrument before a final large pilot with a year 8 group (23 students) at school A that was not participating in the official study.

The final version of this instrument is the one composed of seven questions displayed above. This questionnaire was then applied at the participants' science lessons during the spring term/2017, taking up an average of 30 minutes to be completed (including the demographic questions seen in appendix 2). Students were asked to answer it individually and without consultation to any external source.[45]

Question 1 (Q1) sought to gather information about students' recollection of different scientists, identifying "to whom the students attributed the responsibility or, more generally, the role in developing scientific knowledge" (Gurgel et al., 2014, p. 358). They were asked to write down all the names they knew to guarantee a minimal validity of the information gathered through this questionnaire, avoiding a possible selection of 'only a few names'. It is important to remark, however, that this question was not employed simply as a way of assessing the number of scientists cited (a check-list of scientists), but to open up space and context (by recollecting scientists they had heard about) to the following questions (Q2 and Q3), through which the 'quality'/depth (and not the 'quantity') of their knowledge was being investigated.

Therefore, I am not advocating that students should be stimulated to memorise scientists' names in a 'the more the better' fashion, or even that HOS should be introduced into science lessons through a list of names. Instead, I am interested in understanding what students already know about HOS, being that in the form of names of scientists (a common approach to HOS seen in many science textbooks) or in the form of thinking about countries/civilisations/contexts that were important to science (as evaluated by Q4, Q5, Q6 and Q7). What students really knew about these scientists (their work and who they were) was more important here than how many names they were able to remember. I expected, with these first three questions, to evaluate if knowledge about the names of scientists also implies knowledge about their lives and works, or if students' recollection of scientists is superficial and decontextualised.

[45] Students were given the choice to not participate at this stage, and since the questionnaire was applied in the absence of their teachers, with only the researcher in the room, these teachers were not aware of who actually responded or not to this instrument.

Nevertheless, I need to acknowledge that by asking these students to name scientists the instrument could be conveying a more traditional view of HOS, with the assumption that scientific practices are mainly individualised, ahistorical and cognitive (a product of the individual work of 'geniuses'), rather than collaborative, historical and socio-cultural. In order to partially avoid this scenario and to include those students who tend to remember stories and contexts more easily than names, other questions in the instrument (Q4, Q5, Q6 and Q7) aimed at gathering a more socio-cultural image of science. Furthermore, as argued by Gurgel and others (2014), this type of question helps us to evaluate students' ideas about the contexts (countries/civilisations) where science can develop, including different social aspects and policies. Lastly, Q1, Q4, Q5 and Q6 were also introduced to explore students' immediate view of who usually participates in science, exploring their image of who the important players in science are, both in terms of types of countries (societies) and of people (gender, ethnicity) involved with scientific research.

The data generated through the HOS questionnaire were initially tabulated and counted in terms of scientists cited (Q1), knowledge about their origins (Q2) and work (Q3), important countries to science nowadays (Q4) and in the past (Q5), and other answers about countries (Q6 and Q7). Results from Q1, Q2 and Q3 were plotted in one column graph per school, displaying differences between knowing a scientist (Q1), knowing their origins (Q2) and their work (Q3). Column graphs were chosen to display contrasts between these three answers for each scientist mentioned, and to enable the visualisation of possible patterns. Meanwhile, results from Q4 and Q5 were plotted in two separate pie charts per school ('countries in science nowadays' and 'countries in science in the past') to show the proportion of citations. Q6 and Q7, having received very few answers, were only tabulated and separately analysed.

Following the application of the questionnaire, its initial analysis highlighted the main trends arising from students' answers about important people and places in HOS, and these topics were then further investigated through <u>follow-up interviews</u> with them and their teachers. This choice was based on research in the Science Education field that advocates the use of follow-up interviews to complement questionnaires when studying students' and teachers' views on specific topics, such as NOS (e.g. Driver et al., 1996; Lederman, 2007; Deng et al., 2011). According to Lederman and others (2002, p. 504), interviews after the application of questionnaires can help to ensure the face validity of the instrument items and the investigation of "respondents' reasons for adopting those positions as well".

These follow-up interviews were carried out with a sample of students in nine focus groups (one for each participant class). Each focus group (four-six students, totalling 20% of the participants) was broadly representative of the class community[46], with students from different ability groups, gender (when possible), and ethnicity. These interviews were semi-structured, and with questions intended to cross-check their answers to the instrument and to also gather their perceptions about the reasons behind these answers (see appendix 8 for this interview schedule).

Results from the questionnaire and interviews were also anonymously discussed with their teachers during our follow-up interviews (details in appendix 6). Interviewing these teachers enabled me to build a bigger picture regarding how HOS has been introduced in school, including their perceptions about their students' views on the topic. Furthermore, the data gathered from the questionnaire and interviews were also complemented by the lesson <u>observations</u> already described in the previous subsection. While aiming at answering RQ1, the findings from these observations were also employed to understand the realities behind students' answers to the HOS questionnaire and focus groups.

My goal then was to develop a multi-layered analysis of students' answers to this questionnaire, considering how participants talk about HOS, scientists and countries in science, and teachers' views about their students' answers and their realities regarding HOS. This connection between questionnaire, interviews and observations was inspired by a CR perspective, and aimed at first describing students' views about the contribution of different people and places to science, and then understanding the reasons behind these views. By using this multi-layered interpretive approach, neither specific results nor pre-conceived categories of analysis were expected and/or employed, and students' ideas (both in the questionnaires and in the interviews) were interpreted in connection with their views of school science and with the particularities of their settings, that is, the curricular approaches adopted by their schools, and their teachers' practices regarding HOS and science education.

<u>Answering RQ3 - NOS questionnaire, interviews and observations</u>

Similar to the strategy employed to answer RQ2, the initial source of data for the investigation of RQ3 consisted of an open-ended <u>questionnaire about NOS</u> applied to all participant students, aiming at gathering an overview of their understandings about the topic and at informing a more detailed discussion about its results during future <u>follow-up interviews</u>.

Reviews of the most prominent instruments available in the literature for looking into students' ideas about NOS have been made by several researchers (Lederman et

[46] See appendix 7 for demographic comparison between the participant classes and their focus groups.

al., 2002; Lederman, 2007; Deng et al., 2011; Lederman et al., 2014). The general trend in this area can be summarised by an initial focus on multiple-choice tools, replaced by Likert-scale and Agree/Disagree instruments and, currently, by open-ended and oral forms of inquiry. This shift from quantitative to qualitative instruments is strongly related to several criticisms received by early tools, especially due to their too simple and shallow forms of investigating students' views about NOS (Lederman, 2007). In this scenario, choosing some options or evaluating some statements do not seem to provide in-depth information about what students understand about a topic, since they are being forced to choose between specific options (Driver et al., 1996). Therefore, open-ended questionnaires, associated with follow-up interviews (to validate the initial answers) and analysed from a qualitative perspective (coding and categorization processes) started to be favoured (Lederman, 2007).

Based on these reflections, Lederman and his collaborators have been developing since the 1990s one of the most well-known qualitative instruments to assess NOS understandings, called as ‘Views of nature of science questionnaire’ (VNOS). This questionnaire has been used by various educational researchers around the world to assess students’, teachers’ and scientists’ understandings about NOS, and it has been adapted to different levels of schooling (Deng et al., 2011).

Nevertheless, the approach chosen by Lederman and his collaborators has been subjected to some criticisms, as summarized by Allchin (2011). According to this author, the questions asked by the VNOS are too simple and not very deep in gathering students' understandings of NOS. This is because they are built around generally declarative tenets (which the author classifies as being on the ‘remember and understand’ Bloom's taxonomy of learning), instead of demanding in-depth reflection and analysis from the students (‘apply, analyse and evaluate’, in Bloom's scale).

Allchin (2011) and Deng and others (2011) also state that VNOS questions lack context and authenticity and, if we believe NOS should be included in science lessons through a contextualized and critical approach, then its assessment should also be authentic and context-based, involving problem solving, decision-making and argumentation (Deng et al., 2011; Hodson, 2014a). Also, by using questions that focus on declarative knowledge, these instruments are often employed to characterise students as right or wrong (or naïve and sophisticated) in relation to their views about NOS, instead of developing a more nuanced understanding of how they think about the topic (Allchin, 2011; Deng et al., 2011).

The questionnaire developed in this study was then open-ended and mainly context-based, inspired by the works of Driver and others (1996) and Lederman and others (2002) (through an adaption of the VNOS to an authentic, context-based and decision-making approach), and applied to all participant students (coupled with follow-up focus group with a sample of these students, as done for the HOS questionnaire). This instrument was initially piloted with three sets of 4-5 students from years 8, 9 and 10 at school A in a focus-group style to check for issues with language and comprehension of the questions. A final pilot was carried out with a year 8 group (23 students, not involved in the official study) at school A, aiming at exploring the type of answers the questionnaire was generating and possible methods for its analysis. The final version of this questionnaire contained the following questions[47]:

1. Read the following questions and decide if they are scientific questions or not scientific questions (use a cross X to mark your answer on the table). Please, give your reasons in a few words for each of your choices.
- Which is the best programme on TV?
- Is it wrong to keep dolphins in captivity?
- What diet is best to keep babies healthy?
- Is it cheaper to buy a large or a small packet of washing powder?
- How was the Earth made?
- Is the Earth's atmosphere heating up?

2. Galileo Galilei (1564-1642) was a famous scientist who lived in Italy, at a time when most leading thinkers followed Aristotle's (a Greek philosopher) ideas. At that time, people believed that the Earth was at the centre of the universe (geocentric model) and that the surfaces of the moon and the planets were smooth, uniform and perfectly spherical. Galileo wanted to see whether these ideas were right. In 1609, he constructed his own "home-made" telescope (one of the few telescopes in the world at that time) and pointed it towards the sky. He found out that the surface of the moon was uneven, rough, and full of cavities and bumps, chains of mountains and deep valleys. He also found objects in orbit around Jupiter and not around the Earth, concluding that the Earth was not the centre of everything in the universe. He quickly published his findings, but his ideas were not easily accepted and he suffered a lot of opposition.
a) Galileo faced a lot of opposition from other scientists and the general public to his theories. Why do you think that happened?
b) After some decades, Galileo's theories started to be accepted by other scientists. In your opinion, why did these other scientists start to accept his theories?
c) Do you think that oppositions to new scientific theories still exist today? Why might new scientific ideas be opposed nowadays?
d) Can you give examples of situations or cases where present-day scientists faced (or could face) oppositions to their work?

3. Scientists agree that about 65 millions of years ago the dinosaurs became extinct, but they disagree about what caused this to happen.
The first theory, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction.
The second theory, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction.
a) Why do you think they disagree even though they all have access to similar scientific information?
b) If a scientist wants to persuade other scientists of their theory for dinosaur extinction, what do you think they have to do to convince the others? Explain your answer.

4. Read the following cartoons and answer the questions when they appear:
a) What does "theory" mean in science?
b) How did Tom and Sarah come up with their theories?
c) What could they do to check if their theories are good ones?
d) Does this prove that Sarah's theory had a problem? Why?
e) Which of these theories (Tom's or Sarah's) is best at explaining what happened in both experiments? Why?

5. a) In your opinion, what are the main objectives of scientific work/science?
b) Could you give some examples of things or activities where science is involved outside the school?

6. The model of the inside of the Earth shows that the Earth is made up of layers called: crust, mantle, outer core and inner core.
a) What do you think a "scientific model" is?
b) Does the model of the layers of the Earth show exactly what the inside of the Earth looks like? Why?
c) Knowing that it is very difficult to observe the inside of the Earth, how do you think scientists created this model? Which kind of investigation do you think they used?

[47] A complete version of this instrument, with its images and original layout, can be seen in appendix 9.

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 characterising 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 socio-cultural 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.

It is important to highlight the option of having more than one question in the questionnaire dealing with certain aspects of NOS (e.g. 'controversies in science' is part both of Q2 and Q3) to guarantee some degree of triangulation of students' views about NOS, since they were supposed to employ these ideas about science and scientific work in different contexts and items. This is not to say, however, that students were expected to hold a coherent view of NOS that would be easily transferred from one context/question to another, but this possible situation was in itself relevant to this investigation.

The NOS questionnaire was applied during their science lessons in the summer term/2017, taking up an average of 45 minutes to be completed. Students were asked to answer the questionnaire individually and without consulting any source of information other than their own knowledge about the topic, following a similar procedure to the one adopted with the HOS questionnaire.

Data generated were coded qualitatively (Dey, 1993) as statements developed through an inductive approach. These statements described ideas written by the students about NOS and they were produced as emergent codes for each one of their answers to the six questions (Coffey & Atkinson, 1996; Charmaz, 2014). The final coding system was composed of 37 statements and its reliability was independently checked by two other educational researchers, resulting in an agreement of 85% between three researchers, with most of the disagreements related to language issues (i.e. wording). Table 3 displays examples of the codes alongside their meanings and examples of how students' original answers were translated into the actual codes. The complete coding system can be found in appendix 10.

Table 3. Sample of the coding system for the NOS questionnaire

#	Final code/statement	Description
Question 1		
6	Science is about facts/right answers	Answers that are more specific related to science being interested in finding facts about things and/or fixed/right answers about specific questions and/or proving people wrong (e.g. "it's not scientific because is about choice and not facts").
Question 2		
9	Scientists can resist new or different scientific ideas	Answers stating that scientists can resist new and/or opposite/different ideas/theories, especially if they follow another school of thought (e.g. "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	Answers stating that having access to instruments and other forms of technology can help new discoveries, gathering new data/evidence, developing new ideas/theories, etc (e.g. "They disagree because they researched it using different equipments").
Question 4		
12	A theory/model has to be strongly connected to empirical evidence/ experiments to be accepted	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, etc. (e.g. "they came up with their theories by doing experiments").
Question 5		
1	Science involves investigating and expanding knowledge about people and the world	Answers related to 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, etc.
Question 6		
10	Instruments and technology impact scientific discoveries/ideas	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, etc (e.g. "They can use equipments to develop this model of the Earth").

Each statement could have been employed in more than one specific question (e.g. statement #10 was used by students in Q2, Q3 and Q6 – as seen in table 3 and in appendix 10). In addition, each student's answer to a question (Q1, Q2, Q3, Q4, Q5 or Q6) could end up encompassing one or more statements, depending on how many ideas from the coding system this student was employing to answer each question. For instance, table 4 below displays student X's response to Q2, illustrating how this answer was coded through the combination of different statements from the coding system.

Table 4. Student X's answer to Q2 in the NOS questionnaire

Q2 item	Original answer	Correspondent statement	Set of statements used to code Q2
a	"Because they didn't have a telescope to check"	#10 - Instruments and technology impact scientific discoveries/ideas	#10, #12, #14
b	"Because they started doing their own investigations about it with their new telescopes and found the same evidence"	#12 - A theory/model has to be strongly connected to empirical evidence/experiments to be accepted	
c	"Challenges and oppositions to new scientific theories still exist today because lots of pieces of the world have not been scientifically discovered"	#14 - Disagreement between scientists can occur because science is still in development	
d	N/A	N/A	

The choice of coding through statements was connected to my aim of not categorising students according to specific philosophical/epistemological groups or as a right or wrong (Allchin, 2011; Deng et al., 2011). By using these statements, I was able to portray a more dynamic picture of the participants, in which different ideas/views (sometimes even from different philosophical stances) could be simultaneously operationalised while thinking about NOS.

Furthermore, as argued by Peters-Burton and Baynard (2013), coding through inductive statements can be useful for the adoption of a method of visual analysis of large datasets known as 'Epistemic Network Analysis' (ENA), which was chosen during the pilot of this questionnaire to organise the data generated. Inspired by Peters-Burton and Baynard (2013) and Peters-Burton (2015), this method consists of a mixed-method approach especially developed to show visual interconnections (networks) between ideas (statements) within a group in the form of an 'epistemic map', being helpful for displaying how ideas about NOS are being employed together by the participants.

In order to visualise these epistemic maps (or networks) from whole groups, each student's answer to the questionnaire was individually coded using the coding system (37 statements). If an answer employed more than one statement, then more than one code was attributed to it. For instance, in the case of student X mentioned above, statements #10, #12 and #14 were all used to answer Q2, so these codes were connected among themselves as part of her answer to Q2. The criterion employed regarding these connections among codes was: since all the questions were contextual (except for Q5, which was not contextual but still very straightforward), students were expected to employ the same line of thought at least within each question. For instance, since student X used codes #10, #12 and #14 to answer the same question, we can infer that this student considers that these 3 ideas can be employed together to think about NOS.

Following the procedure described by Peters-Burton (2015), a 37x37 unit matrix was built for each student, with codes from 1 to 37 displayed in rows and columns. Every time two statements appeared together in the same answer [such as (#10 + #12), (#10 + #14), (#12 + #14) for student X], 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, for student X, the cell in the intersection of column 10 and row 12 was numbered as 1; similarly, the intersection of column 12 and row 10 was also numbered as 1.

Afterwards, all 'student-matrices' (individual unit matrices) within a class were added together through matrix addition, generating a final 'group-matrix'. Group-matrices were generated for the groups of students displayed by table 5 below, and each group-matrix was then uploaded to the network analysis software UCINet®, which transformed it into a network, as exemplified by figure 1 below.

Table 5. Group-matrices created for different groups of participant students

Name of the group-matrix	Participant students
All students	All answers from both participant schools
School A – year8	All answers from the participant year 8 at school A
School A – year9set1	All answers from the participant year 9 – set 1 at school A
School A – year9set2	All answers from the participant year 9 – set 2 at school A
School A – year9set3	All answers from the participant year 9 – set 3 at school A
School A – year10set1	All answers from the participant year 10 – set 1 at school A
School A – year10set2	All answers from the participant year 10 – set 2 at school A
School B – year8set2	All answers from the participant year 8 – set 2 at school B
School B – year9set3	All answers from the participant year 9 – set 3 at school B
School B – year10set1	All answers from the participant year 10 – set 1 at school B

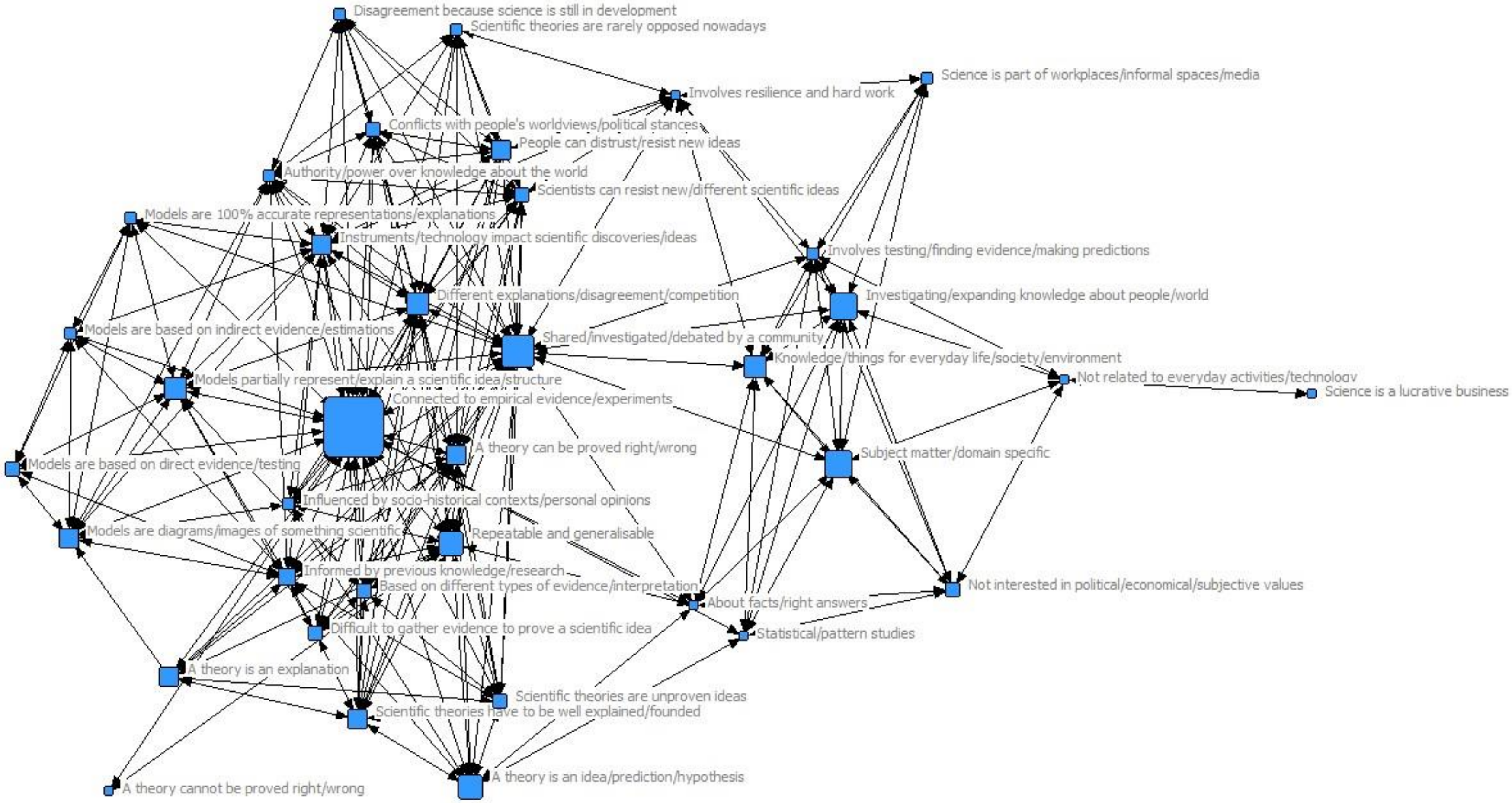

Figure 1. Epistemic Network Analysis of students' answers to the NOS questionnaire – all students

Each node on the map represents one of the 37 statements, whilst the lines show the connections (or not) between these statements in students' answers. For instance, in the case of figure 1, at least one student employed both the statements "Scientific ideas are shared/investigated/debated by a community of people" (#19) and "People can distrust/resist new ideas" (#37) as part of their answer to a specific question.

The distance between the nodes and their locations in the network are also important sources of data: the closer the nodes are on the map, the more frequently they are associated together by the students in their answers (Schaffer et al., 2009; Peters-Burton, 2015). Also, the size of each node is associated with the frequency it was cited by the students, and the total number of statements employed and the density of the network (measured as the percentage of actual connections made by the students among all possible connections available for the total of statements) can be used as indicators of the level of diversity of the ideas displayed by a specific group.

The networks produced here were then analysed in relation to four criteria: the number of ideas and connections employed by the students to talk about science (statements and density); which ideas are the most frequent (size of nodes) and central to students' views about NOS (centrality); which ideas are more closely connected together by students and which ones are less (or not) connected when thinking about science (proximity of ideas).

Understanding the main patterns found when looking at these aspects of the networks entailed, however, an extra step in the analysis of the NOS questionnaire: the development of possible explanations for these answers. Therefore, as for RQ2, follow-up interviews (see appendix 8) with groups of participant students were carried out and analysed as part of a multi-layered approach to the investigation of RQ3. The patterns from the networks were analysed taking into consideration not only students' answers in our interviews about NOS ('cross-checking'), but also how they viewed the teaching about NOS in their science lessons. These results were also discussed with their teachers regarding their teaching realities, resources, and official curricula and assessment (see appendix 6). The analysis developed from my observations for RQ1 was also relevant to this understanding of students' views about NOS, being an important part of the multi-layered analysis proposed for answering RQ3.

4.2. The Implementation phase – methodological strategy

The Implementation phase of this study aimed at developing and implementing, through collaborative work with a science teacher, teaching and learning plans (TLPs) that would incorporate culturally diverse examples and discussions about NOS into school science through the use of an intercultural model of HOS, addressing RQ4 and its following subset of questions:

RQ4. In which ways can an intercultural model of HOS be successfully integrated into school science through TLPs to foster teaching and learning of NOS?

> **RQ4.1.** How can the planning and teaching of these TLPs be carried out to promote the integration of NOS into school science?
>
> **RQ4.2.** In which ways can this approach impact students' understandings of NOS and what are their views about this experience?

The idea with this year-long research phase (carried out during the school year of 2017/2018) was not only to develop TLPs in collaboration with a science teacher, but also to investigate the process involved in teaching these TLPs as part of regular science lessons. Informed by the findings and reflections built throughout the Exploratory phase about current school science practices and students' understandings of HOS and NOS, this second stage of my research then explored the possibilities and hindrances offered by the intercultural model of HOS to the teaching about NOS alongside content from the official curriculum.

Similar to my Exploratory phase, this Implementation phase was developed under a Case Study strategy (Yin, 2003; Stake, 2005) about the work throughout one school year with one specific class (the 'case' under study) at school A. It involved different methods of data generation and a multi-layered and qualitative approach to the knowledge production about the elaboration, teaching and learning from the TLPs.

According to different researchers (Brown & Edelson, 1998; Confrey & Lachance, 2000; Janssen et al., 2013), innovative works in contexts such as science lessons can only be successful through a constant dialogue between the theoretical framework and aims guiding the experience (i.e. the incorporation of the intercultural model of HOS), the regular curriculum, and the role of the teacher within the development-implementation-assessment of the project. Hence, when developed as part of specific academic research such as this project, an innovative experience must take into account not only the realities of the school, class and subject being taught (informed by the findings from my Exploratory phase), but also the role of the teacher.

In a scenario where I was not responsible for teaching with the TLPs, I opted to work collaboratively with the participant teacher to fulfil my research aims as well as the teacher's and his students' expectations towards this new experience. I hoped that this approach would impact both this teacher's professional development (by implementing and reflecting about innovations related to his practices) and my own work (by learning from the teacher's expertise) during this experience (Brown & Edelson, 1998; Janssen et al., 2013; Roblin et al., 2018).

This collaborative work was carried out in three stages organised in an iterative process and inspired by the design principles of 'planning', 'implementing' and 'evaluating' (Edelson et al., 1999; Edelson, 2002; Brown & Edelson, 2003): the collaborative development of a TLP ('pre-teaching' stage); the teaching of this TLP ('teaching' stage); and the subsequent reflection about this experience alongside the teacher before the development of the next TLP ('post-teaching' stage).

The strategy adopted was of implementing one TLP (about a topic from the science curriculum and including both NOS aspects and content) in one half-term[48], totalling four TLPs explored in one school year (each involving 4-5 hours of teaching). This choice of working with different TLPs can be justified by my aims of diversifying the experiences with the TLPs throughout the school year, including the work with different science subjects (i.e. Biology, Chemistry and Physics).

Insights and ideas learned from the work with one TLP would be important to the development of the subsequent ones. The time available between the teaching of each TLP was then employed both as a retroactive moment of reflection about what had worked and what had not worked in the planning and teaching stages of the TLP (a 'post-teaching' stage), and as a space for thinking about learnings and issues that could be relevant to the next TLP (a 'pre-teaching' stage).

Considering my interest in understanding the possibilities and hindrances offered by these four TLPs, I opted to analyse this iterative and collaborative experience through the reflection about agential and structural aspects (Easton, 2010; Scott, 2010). This was done by investigating different aspects closely related to this experience, such as: participant teacher's ownership of the TLPs and views about the experience; students' engagement and interest in the TLPs; impact on their understandings about NOS and on their learning of the regular content; influence of the official curriculum and examinations in the development of the TLPs; possibilities from

[48] Division of the school year followed by school A; each half-term normally comprises six continuous weeks of lessons, followed by a short break (usually one week).

the available scholarship in the field of HOS for the development of the TLPs; among others.

These analytical lenses were specifically related to the type of RQ I proposed to inform this part of my investigation: “In which ways can an intercultural model of HOS be successfully integrated into school science through TLPs to foster teaching and learning of NOS?” Here, important reflections are necessary in relation to what is meant by ‘successfully integrated’ and ‘learning of NOS’. In other words, what does a successful implementation look like? And what are the epistemological and pedagogical conditions, including curricular pre-requisites, to the development and implementation of the TLPs? In order to address these curricular, pedagogical and learning areas behind this experience, three dimensions of analysis were explored – ‘Development’, ‘Teaching’ (both discussed in chapter 6 and mainly related to RQ4.1) and ‘Students’ (discussed in chapter 7 and mainly related to RQ4.2) –, focusing on teacher’s and students’ views about this experience (e.g. enjoyment, discomfort, preferences) and on their learning from it (e.g. teacher’s practice and knowledge growth, students’ talk about NOS and results in their official exams).

This multi-layered approach can also offer my small-scale case study a pathway to reflect upon how this experience can be transformed and scaled-up to other contexts (e.g. other classes, teachers and schools). In this scenario, with this Implementation phase I was also interested in investigating and generating some ideas and implications for the use of the intercultural model of HOS in different settings other than the participant class.

In the next section, special attention will be given to the selection process and characteristics of the students and science teacher involved in this phase.

4.2.1. Setting and Sampling

The participant school in this phase was school A, which had already taken part in the Exploratory phase. School A was chosen due to its interest in engaging with both stages of my research since my first meeting with the Head of its Science department. Having received a good acceptance from science teachers and students at this school during the Exploratory phase, I then opted to invite one of them (teacher F) to work with me in this new phase.

Teacher F (see appendix 4 for more details about him) was, among the participant teachers in this research, one of the most interested in innovative approaches, especially in relation to NOS, despite not having any specific training in HOS or NOS teaching besides his tacit expertise and Initial Teacher Education. During our preliminary interview, he highlighted that teaching about the scientific world and ‘how science works’ was one of his goals and, as it will be further discussed in chapter 5, he had a genuine interest in working with creative lessons and discussions about NOS and also had a positive relationship with his students. The extent to which these teacher F’s characteristics influenced our work during the development and teaching of the TLPs will be explored in chapter 6.

The class chosen to participate in this phase was teacher F’s only KS3 class in that school year (convenience sampling) – a year 8 group of 26 mixed-abilities students (aged 12-13) whose demographic information (obtained through the questions in appendix 2) can be found in appendix 11. This class had three weekly science lessons, two single lessons with teacher F and one single lesson with a new teacher at the school who had not been part of my Exploratory phase.

It is important to remark here that my choice of developing this research phase at only one class and of working only with teacher F was linked to my time constraints as a sole researcher, making it difficult for me to work with a larger group of teachers and students. In this scenario, I have to acknowledge a possible source of bias regarding the data generated by this investigation due to its small-scale nature and to the choice of working with a teacher who had a positive view of HOS, NOS and innovative approaches, aspects that will be also addressed in chapters 6 and 8.

4.2.2. Data generation

This research phase involved different methods of data generation, such as observations, interviews, questionnaires and focus groups, mirroring the multi-method approach adopted during the Exploratory phase. It also consisted of three research stages, as mentioned in the previous section, starting from the collaborative development of a TLP with teacher F, moving on to the teaching of this TLP and then to a reflection upon this experience prior to the development of the next TLP.

Table 6 summarises how this scenario of an iterative and collaborative process behind the development and teaching of the TLPs was connected with my methods of data generation and with my interest in producing a multi-layered analysis of this experience. As shown below, my goal of analysing the work on and with the four TLPs from the development, teaching and students dimensions guided my choice of methods for data generation throughout each stage of the Implementation of each TLP.

Table 6. Outline of the methods of data generation and analysis – Implementation phase

Dimension of analysis	Implementation stage	Main focus of the analysis	Methods of data generation
Development	Pre-teaching	How curriculum expectations and HOS/NOS teaching can be bridged	- Researcher's reflections on the development of TLPs (field notes) - Interview with the teacher (pre-teaching)
Teaching	Teaching and post-teaching	How the TLP is being taught and teacher's perceptions of the experience	- End-of-lesson informal chats with the teacher - Debriefing interview with the teacher (post-teaching) - Researcher's field notes (observations of the lessons) - Teacher's audio-recordings (during the lessons)
Students	Teaching and post-teaching	Engagement and learning of NOS and content	- Researcher's field notes (observations of the lessons) - Debriefing interview with the teacher (post-teaching) - HOS and NOS questionnaires (pre and post style) - Focus groups with students (after each TLP and at the end of the year) - Students' NOS diaries - Students' group mind map - Students' productions during the lessons - Students' results in the official exams

The investigation of the ‘Development’ dimension focused on the affordances and constraints involved in incorporating the intercultural model of HOS into a content-based national curriculum for KS3. I was then concerned with the process of choosing the topic for each TLP[49] and its subsequent development to include both the expected content and NOS under an intercultural model of HOS.

Data related to this dimension were generated through my field-notes and unstructured interviews (audio-recorded conversations) during the development sessions at each pre-teaching stage (planning sessions with total of around four hours for each TLP). Data then comprised teacher F’s and my own reflections about: the possibilities presented by the field of HOS to the use of this intercultural model (examples, cases, availability and access to historical materials); the flexibility of the curriculum in terms of bringing NOS and content together; our collaborative work during this process; time and assessment constraints (how to plan the TLP within the time available and expected content); among others.

The ‘Teaching’ dimension followed naturally from the development dimension, being related to the next stage of the experience – the teaching of the TLP by teacher F – and encompassed two main levels: the teacher’s own impressions about the teaching of the TLP, and my study of how it was actively being taught by him. Thus, it involved teacher’s views on positive and negative aspects of the experience, including discussions about time and pedagogical constraints, students’ engagement, pedagogical practices, and comfort with HOS and NOS teaching. Data related to these aspects were generated through quick chats at the end of each lesson and post-teaching debriefing interviews (at the end of each TLP).

Additionally, this analysis was also informed by data generated during the teaching of each TLP through participant observations of the lessons (researcher’s field notes) and audio-recordings of teacher F. These observations explored the same aspects investigated during my Exploratory phase (e.g. examples the teacher is using; how he is using these examples; work with NOS; uses of HOS), being also informed by the analytical themes developed in that previous phase. Alongside the recordings, these observations informed the second level of this ‘teaching dimension’: how the TLP was being implemented by the teacher, including if and how he adapted and transformed these resources during the lessons.

The final dimension of analysis (‘Students’) was concerned with the impact of the TLPs on students, both at the interest and learning levels. The former was related to students’ reception of the TLPs as a whole and of specific tasks and discussions.

[49] The four chosen topics were: Medicines (Biology), Magnetism (Physics), Evolution (Biology) and Earth’s resources (Chemistry). Since the selection of these topics was an integral part of my analysis of this experience, this process will be further discussed in chapter 6.

Data were generated through: researcher's field notes from the lesson observations; debriefing interviews with the teacher; extra questions in the HOS questionnaire applied at the end of the Implementation phase (see appendix 12); and a final follow-up interview with a group of six students at the end of this phase (see appendix 13 for interview protocol).

Meanwhile, the learning level addressed their engagement with NOS, investigating if the TLPs offered them learning opportunities explicitly related to these ideas, and how that affected or not their talk about NOS. In addition, this level also looked into students' results at their end-of-year exam, applied during the final half-term of this school year. The aim was to evaluate possible impact (positive, negative or neutral) of these materials on their exam results, an important analysis in light of curricular constraints faced by teachers (de Berg, 2014b; Clough, 2018). In order to analyse this level data were generated through different methods at distinct stages during this research:

- HOS and NOS questionnaires: both applied and analysed as done in the Exploratory phase. This process followed a pre- and post-implementation design: both questionnaires were applied at the beginning of the school year (first half-term) before the teaching of the first TLP ('pre-implementation'), and then again at the end of the school year (last half-term) ('post-implementation'), mapping possible impact of the TLPs on students' views about NOS. It also included follow-up interviews in the form of focus groups with these students after the application of each set of questionnaires (pre and post-implementation). The pre-implementation interview was guided by the protocol seen in appendix 14 and carried out with five groups of four to five students (totalling 24 participants). Meanwhile, the post-implementation interview was carried out with one group of six students (same group mentioned above) and guided by the interview protocol in appendix 13, a shorter version of the pre-implementation one due to time constraints at this point of the school year.

- Students' diaries about NOS: short paragraphs written, whenever possible, at the end of each lesson of each TLP to map short-term impact of specific lessons on NOS ideas. Students were asked to write these paragraphs guided by the question: "what did you learn today about how science and scientists work?"

- Group mind map: developed by one group of five students at the end of each TLP (a different group for each TLP). This work was guided by me in an unstructured format and involved asking them to think about what they had learnt about the topic taught in the previous lessons, and then to collaboratively draw a mind map connecting all these ideas. My approach here was to start by prompting them to annotate on the map anything they had learnt during the lessons, not necessarily focusing on content or NOS, but on anything they deemed important about the topic. Throughout this process, I then encouraged them to establish connections between different annotations by asking generic questions, such as “what else did you learn about this?”, “how is this connected with that?”, “is there anything else you want to add to this part?”, “how do we know this?”, among others.

- Students’ productions: materials produced by students as part of specific tasks carried out during the lessons (including homework).

- Students’ results in their end-of-year exam: averages from all year 8 classes (anonymised) collected by teacher F from the school’s database, aiming at comparing the participant class’s results to the average from other year 8 classes at school A.

4.2.3. Data analysis

The strategy informing the presentation of the findings and the analysis of this Implementation phase was of constructing a narrative following the stages involved in the development and teaching of the TLPs, that is, focusing on the pre-teaching, teaching and post-teaching moments. The writing of this narrative was divided into the three main dimensions explored here: Development, Teaching and Students.

The findings and analysis related to each one of these dimensions involved a constant comparison between the experiences of developing and implementing each TLP, that is, commonalities and dissonances in the work with each TLP were identified and further interpreted. This interpretive approach (Dey, 1993; Elliott & Timulak, 2005) was informed by the CR perspective already discussed in chapter 3, encompassing then stages of ‘descriptions and search for patterns’ between the TLPs, followed by the exploration of possible causes for patterns and dissonances between the TLPs (‘retroduction’ process), and then looking for connections between these findings/interpretations and the literature in the field of (Science) Education (‘theoretical redescription’ process) (Given, 2008; Scott, 2010; Fletcher, 2017) around pedagogical strategies, teacher’s professional development, teaching and learning about NOS and HOS, teaching innovation, development of resources, among others.

All the data generated specifically in the case of the Development and Teaching dimensions (mainly in the form of field-notes, and of audio-recordings of lessons and my meetings with teacher F and his students) were analysed as a whole, that is, as a set of different types of data that were informing a multi-layered understanding of how the development and implementation of these TLPs came about. This multi-layered approach involved looking at this set of data and trying to understand this experience from my perspective as a researcher (focusing on the scholarship available in the field of HOS, on the availability of teaching resources and on the official curriculum to be followed), from teacher F's perspective (including agential – e.g. comfort with his own HOS and NOS knowledge and with our collaborative work – and structural aspects – e.g. scheme of work, time available for the experience, and students' learning of content), and from his students' perspective (e.g. engagement with the lessons as a whole and with specific types of tasks proposed by the TLPs).

For the 'Students' dimension, results from the participant class's end-of-year exam were compared to the average for all year 8 classes at school A through statistical analysis (t-test). My aim was to evaluate to which extent this experience influenced the participant students' results in their exams when compared to other year 8 groups at the school. That would allow us to better understand its affordances and constraints to school A's realities of summative assessment.

In addition, the use of questionnaires entailed an additional form of analysis to the other two dimensions, involving quantitative aspects and coding steps. Here, the analytical strategy was the same as the one employed for both questionnaires during the Exploratory phase (including the use of ENA for the NOS questionnaire[50]), with an extra step taken to qualitatively compare the results between pre and post-implementation results to evaluate, at least partially, effects from the experience on students' ideas about NOS and HOS. The findings from the questionnaires were also analysed in conjunction with their other productions, such as diaries and group mind maps, as well as with their interviews and with the findings from the other two analytical dimensions (Development and Teaching).

It is also worth noting that in this analysis I put a larger emphasis on looking into students' ideas about NOS as compared to their answers to the HOS questionnaire. This is linked to the main goal of this research – broadening and diversifying teaching and learning about NOS – where HOS (represented here by the intercultural model) was employed was a vehicle to inform this experience, rather than being a chief intended learning outcome in itself.

In summary, this comprehensive connection between the impact of the TLPs on the students dimension and how the TLPs were developed and implemented aimed at generating an overall understanding of this experience by taking into account not only how it impacted students' knowledge, but also how the choices made throughout the pre-teaching and teaching stages (and other possible factors) yielded these results. In

[50] The coding scheme employed to analyse the NOS questionnaire during this Implementation phase, found in Appendix 15, was an updated version of the one used during over the Exploratory phase.

chapters 6 and 7, these findings and analysis will be presented in the form of a narrative of the experience. The final chapter 8 will then include more specific discussions about the affordances and limitations of the intercultural model of HOS to school science and about the implications of this study to future research in the fields of HOS and NOS, as well as to curriculum and resources development and school practices, including a reflection about scaling-up this experience.

Chapter 5: Exploratory phase – NOS, HOS and intercultural perspectives in school science

Throughout the Exploratory phase I investigated the presence of HOS, NOS and intercultural approaches in science lessons, paying special attention to teaching practices and students' perspectives and knowledge about these topics. It was my aim here to employ the knowledge built during this phase in the development of the Implementation phase, whose main goal was to introduce new approaches to HOS and NOS into science lessons.

This chapter then presents and analyses the main findings from this first phase, which will be organised according to the three RQs addressed by this stage. In section 5.1 I will explore RQ1, focusing on my observations of science lessons and interviews with participant teachers and students. Sections 5.2 and 5.3 will introduce findings and discussions about, respectively, RQ2 and RQ3, including connections between the results from the HOS and NOS questionnaires and lesson observations and interviews.

5.1. HOS, NOS and intercultural approaches in school science: a view from the classroom[51]

In this section I will discuss data generated during my observation sessions at the participant schools, addressing RQ1: "What are the possibilities and obstacles found in teachers' practices and realities for the inclusion of intercultural aspects of science into school science?". My aim here was to investigate school science's realities, possibilities and hindrances to the introduction of NOS into regular lessons through an intercultural perspective, which will be further explored in my Implementation phase.

The choice of carrying out lesson observations was intrinsically related to this RQ, focusing on science teachers' existing practices, especially on the examples they employed in their lessons and on whether and how they incorporated discussions about NOS and HOS. In addition, these observation sessions, coupled with interviews with the participant teachers, added to my multi-layered (inspired by CR perspectives discussed in the previous chapters) understanding of how they think about, plan and teach their lessons, and how students participate in these lessons.

[51] A shorter version of this section was published as part of a journal article (Gandolfi, 2017).

The coding of the observation sessions was informed by inductive strategies of thematic analysis: developing, comparing and collapsing themes as forms of analytic description of the investigated events. Employing my research topics as sensitising ideas and constantly analysing and comparing new incidents helped me to develop the preliminary codes into four overarching themes that will be used to inform my analysis of school science practices in relation to HOS, NOS and intercultural perspectives: ‘Drawing on examples’; ‘Interacting with students' knowledge and interests’; ‘Connecting knowledge with socio-scientific contexts and people's lives’; and ‘Talking about science and its nature’. In the following subsections, I will define these themes and present relevant data employed in their construction.

5.1.1. Drawing on examples

Drawing on examples was a major part of the lessons observed, and they varied in number (one or more than one), type (item or case) and usage (illustrative, contextualised, or in-depth/critical thinking), as summarised by figure 2. Examples are understood here as samples/representatives of an idea/content that are selected by the teacher to illustrate, contextualise or promote in-depth/critical thinking about this idea, and the diagram below displays their main characteristics. It is important to remark, however, that not all these types and usages of examples were found in every lesson; in some cases, a whole lesson involved only one example explored in a contextualised way, while in another lesson a teacher would opt to explore several examples in a mix between illustrative and contextualised approaches, for instance.

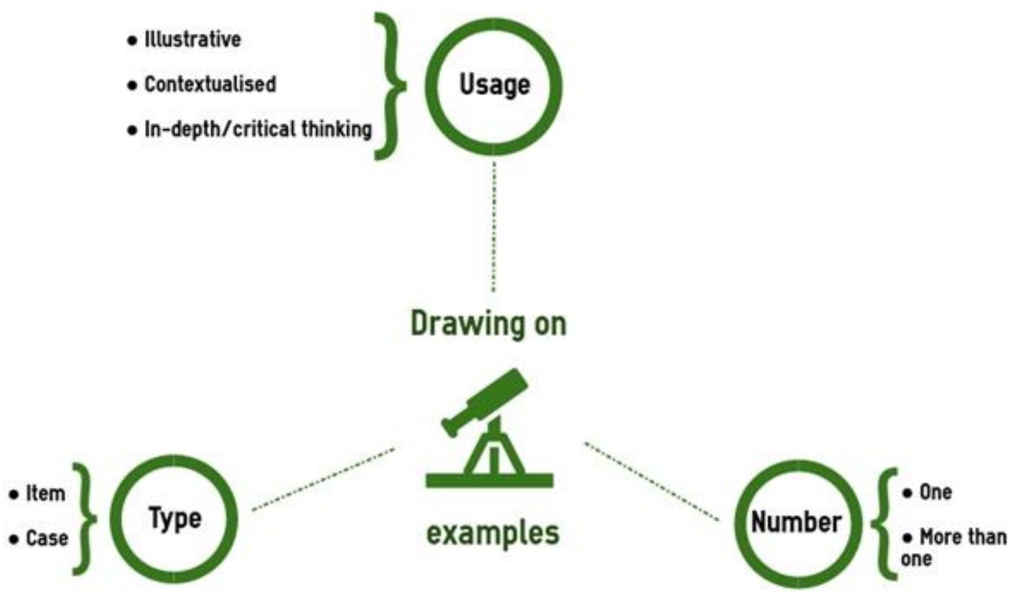

Figure 2. Number, type and usage of examples employed in the lessons observed

First, while the different ways in which examples were used by the teachers can be linked to active/intentional choices made by them based on the topic of the lesson and time available, we cannot ignore a certain level of tacit decisions involved in selecting these examples. That is, while some of these choices were pre-planned and linked to teachers' particular aims for their lessons, their reliance on ready-made resources and textbooks was also identified in this study, often making it complex to assess their original intentions when using specific examples. Nevertheless, some general trends and ideas can be explored here.

Regarding the <u>number of examples</u>, teachers were seen using a <u>sole example</u> (a 'theme' for the whole lesson) or following it up with <u>subsequent examples</u>. Teacher B, for instance, employed different examples throughout his lesson on Endo/Exothermic reactions: glow sticks, respiration and combustion (as examples of exothermic reactions); hand warmers and hydrated copper sulfate (to introduce the idea of reversible/irreversible reactions and energy changes). On the other hand, teacher P opted for an example that acted as a theme for one of her lessons on the Earth's Atmosphere topic: Crude Oil. By working with this theme, she was able not only to gather students' previous knowledge, but also to use it as a context for revising different scientific concepts, such as chemical symbols, mixtures, compounds, intermolecular forces, and hydrocarbons.

These initial examples show the variety of sources teachers can use to develop their lessons, drawing from objects like glow sticks and hand warmers to more complex themes such as crude oil. Table 7 below displays the selection of examples I will focus on throughout this section to illustrate teachers' choices and usages of examples.

Table 7. Selection of examples from the lessons observed

Example	Type of example	Usage of example	Teacher(s)	Class(es)
Hand warmers/glow sticks	Item	Illustrative	**B**	Year 9 (sets 1 and 3)
Fuel choice	Case	In-depth		
Thalidomide	Case	In-depth	**F**	Year 8 (mixed)
Selective breeding in China	Case	Contextualised		
Ebola epidemic	Case	In-depth		
Emma Watson's dress	Item	Illustrative	**P**	Year 10 (sets 1 and 2)
Crude oil	Item	Contextualised		
Magnets in everyday life	Item	Illustrative	**A**	Year 8 (set 2)
			F	Year 8 (mixed)
Darwin's and Wallace's works	Case	In-depth	**A**	Year 8 (set 2)
Ideas about Earth and universe (Flat Earth; 12 pillars; Turtle theory)	Item	Contextualised	**K**	Year 9 (set 3)
Radioactivity research	Case	Illustrative/Contextualised/ In-depth		
Cultivating Stem Cells	Case	In-depth	**K**	Year 10 (set 1)
			F	Year 9 (set 1)

Looking at table 7, teachers seem to usually work with two different types of example: specific item or case. 'Specific item' is an example of a single idea (such as the Turtle theory) or material entity (such as hand warmers, glow sticks, Emma Watson's dress, or crude oil). Among this type of example, the most common instance was using objects from everyday life, with less attention dedicated to material entities or ideas coming from other historical, technological, and cultural contexts. There were, however, lessons where teachers opted to expand their repertoire of items, such as teacher K's work with Ideas about Earth and universe (involving 'specific items' such as: the flat Earth in the Chinese tradition, the 12 pillars in the Indian tradition, the Hindu Turtle theory, among others).

‘Case’ is an example where a specific event happened, is happening or can happen. A case can be, for instance, investigating which fuel (methanol and butan-1-ol) is better in terms of energy released during their combustion through an experiment, as proposed by teacher B in his fuel choice example, or discussing Darwin’s and Wallace’s historical cases during a lesson on Evolution with teacher A. Teacher F’s choices of examples were mainly within this category, exploring a large variety of cases, such as the thalidomide case, selective breeding in China, and the recent Ebola epidemic in Africa.

In general, working with ‘cases’ enabled teachers and their students to build a dynamic way of thinking and talking about scientific concepts, where different aspects informing the case were analysed to understand the context, implications, participants and science involved in the situation under study. Therefore, the types of examples explored in a lesson were also closely linked to how they were used by the teachers, and three types of usage were identified in this study: illustrative/factual, contextualising, and in-depth/critical thinking.

The illustrative/factual approach is characterised by a superficial mention of the item/case as a representative of an idea, without any further discussion about its specificities, contexts or implications. That is, it is an example employed solely to illustrate the topic and that could be easily replaced by any other equivalent item/case without any changes to the lesson. Examples of this approach were: stating that Emma Watson's dress was made of plastic from crude oil or mentioning objects from everyday life containing magnets. Interestingly, the choice of everyday life objects as examples was usually explored through this illustrative approach, with teachers often presenting these items without further delving into them, as done by teacher B when using hand warmers and glow sticks as examples of endo/exothermic reactions.

There were, however, moments when teachers explored examples through a contextualised approach, addressing their implications and/or importance to a specific context, and considering this context as integral to the understanding of the example. That was the case of teacher K’s work with the radioactivity research examples, where she talked about Henry Becquerel’s study of radioactive rays, including information about how his experimental choices had led him to his discovery. This strategy is clearly different from her choice, in the same lesson, of only mentioning Ernest Rutherford as the discoverer of the alpha, beta and gamma rays, without attention to the context of discovery (i.e. an illustrative approach).

Also in a contextualised approach, Teacher P connected her discussion about the crude oil example to different types of fuel pumps found in a local supermarket, emphasising the importance of contextual thinking for understanding the example and its significance:

> Teacher P: “So, there's sulfur in crude oil. OK? **When we burn a fuel that has sulfur, so if you go just to Tesco down the road, it has 2 pumps: ultrasulfur and just normal. Why do you think ultrasulfur petrol, you pay more for it, meaning what?**”
>
> Student A: “Less sulfur!”
>
> Teacher P: “Yes, the sulfur has been removed from it. OK? **There's a process that crude oil companies can do that can remove that sulfur, then you pay more for it**, meaning that if my car was running on ultrasulfur petrol, I'm going to produce less sulfur dioxide in the air meaning that will be less sulfur dioxide to make that sulfuric acid.”

A third way of exploring examples was the <u>in-depth/critical thinking</u> approach, where scientific concepts and/or results were discussed at different levels: conceptual (e.g. symbols, theories, models), contextual (e.g. implications to a specific context/scenario) and critical reasoning (e.g. making distinctions, comparisons, predicting impact, making interpretations, considering alternatives and reliability).

Teacher P's work on the crude oil example, for instance, moved forward to the introduction of environmental discussions on fossil fuels. Her choice of questions involving conceptual (understanding the chemistry of combustion), contextual (impact of combustion on the environment) and critical thinking levels (assessing the causes and consequences of choosing to use or avoid fossil fuels) seems to have helped her to move her lesson from abstract reasoning in Chemistry (intermolecular forces, covalent bonds, hydrocarbons) to a socio-scientific level of work with her students.

Similarly, teacher F’s lesson about drug trials fostered learning of scientific concepts (such as types of drugs, stages of drug trials, placebo effect, double-blind test) and critical thinking about this topic (such as alternatives to animal testing, relevance of each stage of drug trial, ethical and moral considerations, impact on peoples’ lives) through the exploration of the thalidomide and the Ebola epidemic cases. Teacher A also employed a historical and in-depth approach in her lesson on Evolution, discussing the importance of Darwin and Wallace to the development of this topic, and talking about the impact of their travels around the world and of ancient farming techniques and knowledge about selective breeding on their studies.

In summary, examples found during this investigation were varied, and there seems to be an association between them and how they were explored by the teachers. This use of examples can also be connected to teachers’ interactions with students' knowledge and interests, with everyday life examples and open discussions and questions being often taken into account. In the next subsection, special attention will be paid to this type of interactions observed in the lessons.

5.1.2. Interacting with students' knowledge and interests

Interactions are understood here as verbal moments during the lessons when teachers and students actively talk about a particular topic, idea, question, or example. Several types of interactions were observed in this study, such as those related to students' behaviour (e.g. asking for silence), teachers' explanation of a concept, or students' questions about a concept.

Nevertheless, here I will focus on the connections between interactions and the examples discussed in the previous theme, more specifically on how they were linked to students' knowledge, interests and opinions (as seen in figure 3). This analytical choice was made because interactions that foster participants' engagement with the examples being used and with students' previous knowledge, interests and opinions were an important part of this Exploratory phase, since they can be used as strategies to introduce NOS, HOS and intercultural perspectives into school science, as argued in the field (Clough, 2006; 2008; Höttecke et al., 2012).

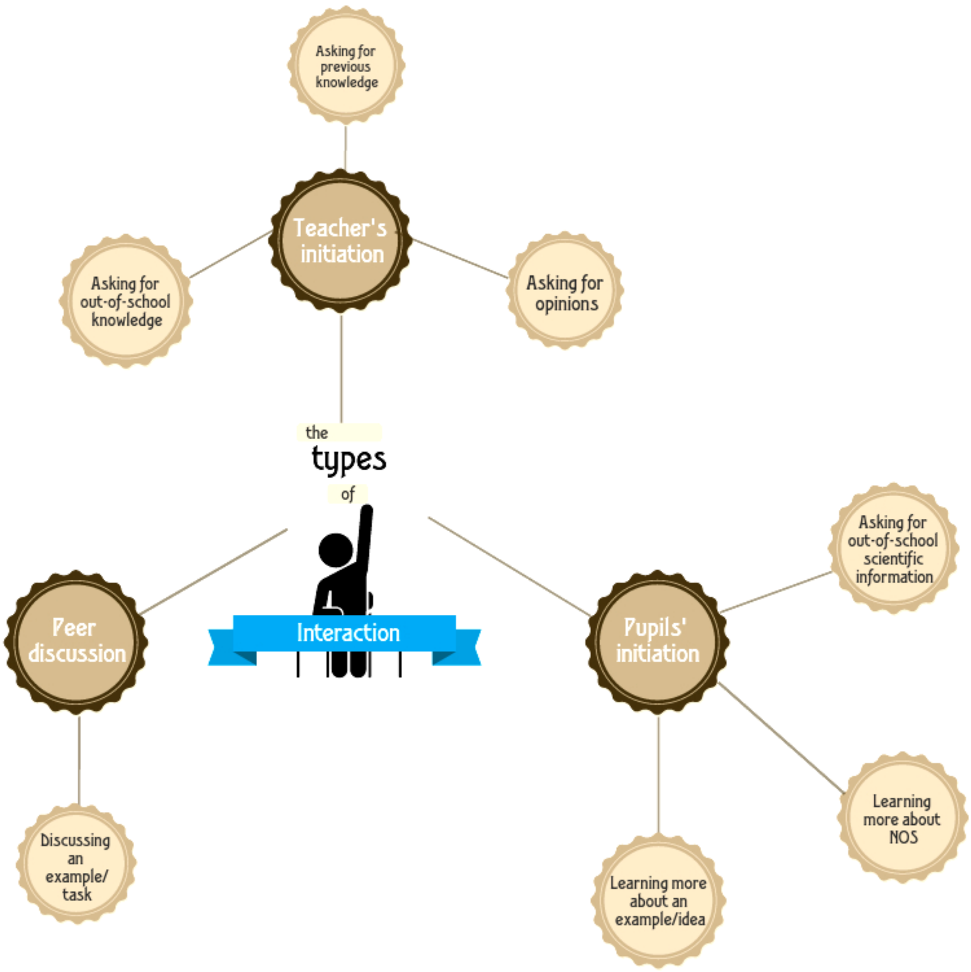

Figure 3. Types and content/purpose of interactions with students' knowledge and interests

Teacher's initiation represents the most prevalent type of interaction observed during these science lessons, with the exchange ‘teacher's question-student's answer’ making up for most of them. Regarding the purposes of these interactions, they ranged from asking about answers for exercises to more constructivist goals (e.g. asking about previous knowledge). In this research, I focused on the latter, when teachers asked their students for previous knowledge, out-of-school knowledge, and opinions due to my interest in investigating possibilities and obstacles to the inclusion of discussions about NOS, HOS and intercultural perspectives into school science.

Asking for students’ previous knowledge can be related to the goal of learning what students already know about the topic being taught. In these cases, the purpose was to connect a new concept/idea/task to topics these students had previously learnt or to any initial ideas they might have about it. Teacher B, for instance, adopted this type of interaction in his work around the fuel choice example by asking about the variables in the experiment they were going to carry out:

> Teacher B: “I think it's a straightforward practical. If we can all start working on the design of our table. So what's the thing that we are going to change? **What's our independent variable?** Someone?”
> Student A: “The amount of acid.”
> Teacher B: “Well done! Right, it's the volume of acid added, and it's in the units of cm^3. What are we measuring each time we add this acid? **What's my dependent variable?”**
> Student B: “Temperature?”
> Teacher B: “Brilliant! All right? It's temperature.”

Asking for previous knowledge was a relevant part of most teachers' interactions with their students during the lessons observed[52]. These questions were usually connected to their examples and served their purpose of engaging with students’ knowledge about the topics when in contact with new ideas. Additionally, teachers also adopted this question-answer strategy, though to a lesser extent, to ask for students' out-of-school knowledge (from everyday life and/or media). Teacher A’s option of asking her students to think about magnets in their everyday life and how they can be part of important objects is an illustration of that. Similarly, teacher P’s work on the crude oil case involved talking to her students about what they might have heard on the news that week about winters in the UK “becoming hotter”.

Some teachers also initiated interactions involving students’ opinions and ideas. In this case, they were interested in learning more about these opinions and ideas to complement their lessons with students’ own perspectives. While exploring the

[52] Interactions such as ‘asking for answers to exercises’ were in fact the most prevalent type during these lessons, but since they are not the focus of this investigation, they will not be analysed here.

cultivating stem cells example, for instance, teacher K asked her students to reflect and give their opinions about harvesting embryonic stem cells and the connection between this technique and debates on life, abortion and IVF.

This approach towards students' opinions was also seen during teacher A's lesson about Darwin's and Wallace's works on the theory of Evolution, where she spent some time stimulating her students to think about and discuss the differences between Evolutionism and Creationism. Teacher K's use of the ideas about Earth and universe case also involved not only discussing and socially and culturally contextualising different views on how the Earth and universe originated (e.g. Flat Earth, 12 pillars, and Turtle theory), but also stimulating students to explain and discuss their own views on the topic.

In contrast to teacher's initiations, students' initiations were less common during the lessons, indicating a more teacher-centred scenario, at least in relation to who was asking and who was answering the questions. Usually, the purpose of these students' initiations was to check their own work or to ask for help with a task, but here I will focus on, as done for the teacher's initiation, instances where they asked for out-of-school scientific knowledge, to learn more about an example/idea or to learn more about NOS.

Asking for out-of-school scientific knowledge was a common situation in several lessons, highlighting these participant students' curiosity about science and how out-of-school knowledge can also be integrated into regular science lessons. In teacher B's demonstration of exothermic reactions with atomic model kits that happened as part of the fuel choice case, one student asked about the discovery of a new chemical by a girl in the USA that he had seen on the news[53]. Teacher B then carried out a conversation with him about chemical elements and their discovery:

> Student C: "**Have you heard about a little girl in America, she created like a new chemical using a set like this?**"
> Teacher: "No! I haven't heard this."
> Student C: "She created it and it was really like, she asked her science teacher 'is this a natural element?' and he sent it to a university and they created it... **but it really might be something possible?**"
> Teacher: "So, it's really possible, ok? So you know, if I show you in your planner the periodic table, what makes these elements all different is to do with the number of protons, the atomic number. So hydrogen is the chemical that has one proton in each atom; helium has 2; and then we can go up to lithium, beryllium. So they've been discovered all the way up to having 112 protons, ok? So if you wanted to discover a

[53] For more information: http://now.humboldt.edu/news/not-your-average-fifth-grade-assignment/

new one, all of these are taken. But if you've found an atom that had 113 protons, well that one has not been discovered, so you have a new atom there."

Student C: "**Yeah, but how would you be able to show that?**"

Teacher: "How would you show it's a new element? Again, you wouldn't be able in a laboratory like ours, because we haven't got the equipment for it, but maybe you might test it for certain properties, it might behave in a different way to other materials that you've seen […]."

<u>Learning more about an example/idea</u> is related to students asking for more information on the example or idea that was already in discussion, usually to further their knowledge or to check their understanding about it. That was the case of teacher F's work on the cultivating stem cells example, where some students asked if it would be possible to guarantee that a person would have twins through an IVF treatment. Likewise, teacher K's students were very interested in further understanding the benefits from cultivating stem cells to the treatment of different diseases, asking if their own specific health problems, such as short-sighted vision, could be solved with the help of this type of research.

Students also asked questions about <u>aspects of nature of science (NOS)</u>, which were mainly connected to understanding some stage, external influence/impact and/or ethical aspects of a scientific process. It is important to remark, however, that students did not necessarily know that these questions were related to NOS. This means that many of these initiations were in fact only implicitly connected to NOS when the questions were made, with teachers' answers bringing (or not) the aspects of NOS into light. For instance, after learning about the case of selective breeding in China, some of teacher F's students asked about the costs of breeding dogs (why dogs with pedigree cost so much). He then talked about how many modern scientific developments usually involve a long-term commitment, with many stages, improvements, drawbacks and investments, resulting in a costly product.

<u>Peer discussion</u> was also part of the lessons and encompassed students working in pairs or groups on exam questions. Occasionally, students also worked together on a task to exchange their views and knowledge on it, to compare and confront information, or to engage in debates. This can be illustrated by teacher K's work on the cultivating stem cells example, where students spent one hour in groups discussing the pros and cons of stem cell research and then debated both their personal views and scientific conclusions about the topic. A similar approach was chosen by teacher F in his exploration of the Ebola epidemic case and its relationship with animal testing, with groups of students debating different views and pieces of scientific information on animal testing of vaccines.

In summary, the types of interaction established during these lessons were mainly characterised by a question-answer approach initiated by the teachers. These questions were usually connected with the examples they had opted to explore and were employed to introduce an idea and to probe students' understandings, including their previous knowledge and opinions.

5.1.3. Connecting knowledge with socio-scientific contexts and people's lives

Even though teachers often tried to connect their examples with students' lives, the level in which these connections were made was variable. In some cases, the idea of ‘people's lives’ was part of the lesson under an illustrative perspective, as seen in the examples of hand warmers and magnets already mentioned here. Nevertheless, this analysis focuses on a different approach, where the impact of scientific research and knowledge on people's lives (and the world) clearly involved discussions about socio-scientific contexts/issues (SSIs) and/or applied science. This choice was made due to the potential that SSIs and applied science topics for the introduction of NOS (Ratcliffe & Grace, 2003; Sadler, 2011; Kyza & Levinson, 2014; Bencze, 2017) and intercultural perspectives (Morin et al., 2011; Erduran, 2014; Ideland, 2018) into science curricula.

Discussions about socio-scientific contexts/issues usually involved the connection of specific scientific content to societal aspects, such as politics, health, ethics, economics and environment, comprising both positive and negative aspects of this relationship. Teacher P’s follow up work from her crude oil example, for instance, included a game where students had to analyse different actions (e.g. going vegan, using nuclear power) and predict their consequences to Global Warming. As seen in figure 4 below, each group of students was given some ‘facts’ about a specific action (e.g. use nuclear) and they were asked to predict the effects of this action on people, money and environment. Here, although discussions about what ‘predictions’ entail and what these ‘facts’ mean and where they had come from were not explicitly carried out by the teacher, students were encouraged to think about these ideas and employ them to carry out the task.

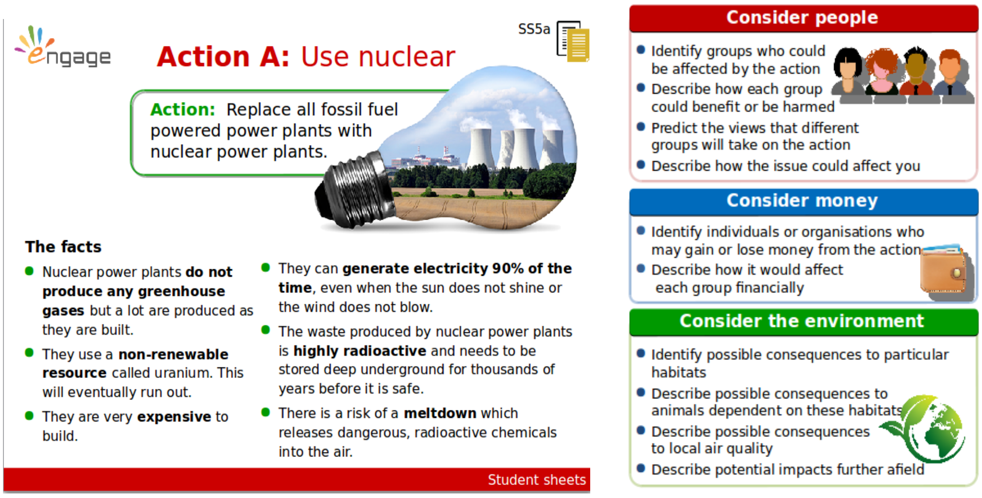

Figure 4. Action-consequence task[54]

Throughout this activity, teacher P stimulated her students to “move beyond the usual environmental predictions” by asking them to also make predictions about social and financial effects. As seen in figure 5 below, which illustrates the work produced by one group of students, this understanding of SSIs as more than environmental aspects created a scenario where students also reflected upon other less examined elements and the inherent complexities involved in this type of topic, such as: “it costs a lot of money to maintain”; “it could lead to cancer”; and “the country would have enough money for research”.

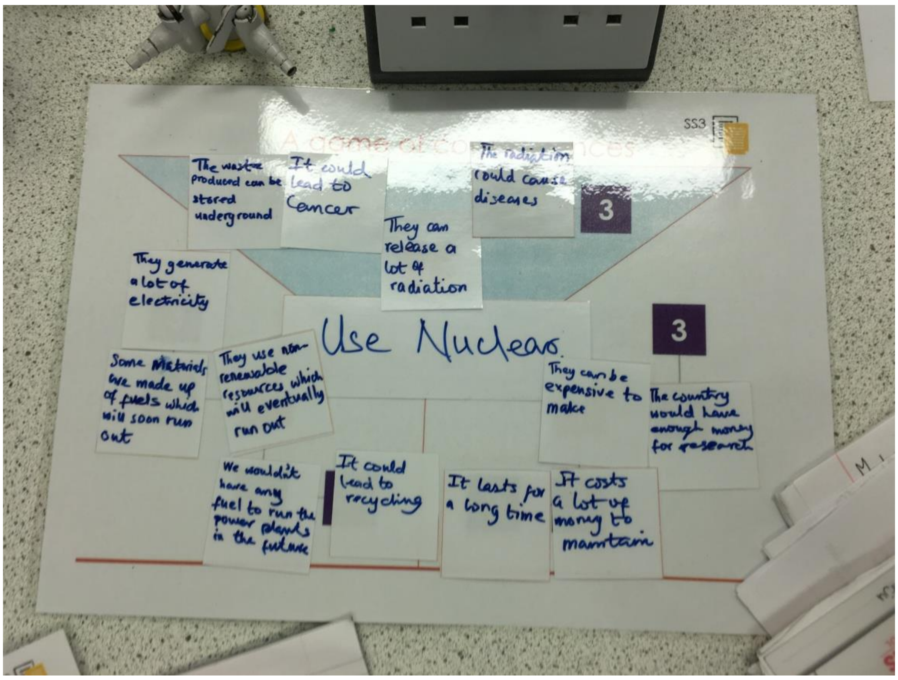

Figure 5. Example of students' work on the Action-Consequence task

[54] Source: https://www.engagingscience.eu/en/

In a similar in-depth approach to connections between scientific development and people's lives, teacher F used the thalidomide case to introduce a discussion on the importance of trials when developing new medicinal drugs. While contextualising this historical case, he highlighted the failure of the drug company in testing the drug with pregnant animals before its release to the public. The use of HOS here as a way of contextualising the example provided students with a concrete case around the impact of science on people's lives and ethics:

> Teacher: "On the table there are 3 sets of humans and they all have been born with something in common with each other. **What's that thing they've got in common?**"
> Student D: "**All have disabilities."**
> Teacher: "Yes, what's specifically, looking at it, what do they got as disability?"
> Student E: "**They got like no arms, no normal legs**..."
> Teacher: "They've all got short arms, short limbs. If you look at their hand and their feet as well, they've actually got different number fingers, ok? **All 3 of those individuals, you can see from the black and white photos, it must be from a long time ago, so they've been born back when there were black and white photos. They were all given the same drug, ok? Indirectly actually, they were not directly given the drug. Anyone know what drug this might be?**"
> Student F: "It's thalidomide?"
> Teacher: "Yes, where did you see that?"
> Student F: "It's over there!" [points to the slides].
> Teacher: "Well done! […] So all these 3 sets of individuals, **they were all babies in their mothers' tummies**, all right? Now when ladies are pregnant, part of the side effect of being pregnant is something called **morning sickness**. Have you heard of it?"
> Students: "Yes!"
> Teacher: "Ok, so it's called morning sickness cause it's exactly what it says in the term, when you feel a bit ill, it's feeling sick in the morning, it doesn't have to be in the morning actually, but typically it's in the morning. **Well, they found a drug that they could give to the moms of these babies and it would make they feel better, they wouldn't feel sick any more. Right? Sounds good yeah? Cause waking up every morning feeling sick is kind of crap. Right? Now, what they failed to do when they were testing this drug is a very important step if you're testing something on women who are pregnant, ok? In fact, because of this drug we now changed the way we test drugs.** What they ended up doing is giving this drug to these ladies and they failed to test on pregnant animals. They've been testing on normal animals, they've been given thalidomide to rats or rabbits that were all feeling sick and they found rabbits and rats weren't feeling sick any more, but what they didn't do is give the drug to rats and rabbits who were pregnant. All right? **If they had done that, they might have found that the rats and rabbits that were then born after giving the drug had disfigurements in their arms and legs.**"

Despite also paying attention to the impact of scientific knowledge on people's lives, discussions about applied science focused on the benefits of scientific work to everyday life, usually in terms of developing new technologies/appliances or solving problems, such as better computers, new materials and drugs. While most of the examples related to applied science were explored quickly and through an illustrative approach by the participant teachers, one instance of further development of this type of example was seen in teacher F's work on the case of selective breeding in China. In this case, he connected this historical technique with the domestication of dogs into pets by humans and with the creation of new and more resistant types of vegetables (such as carrots, bananas and mustard) and textiles, also including discussions about knowledge and technological dissemination, ethical and financial issues, as seen in a student's question about dogs with pedigree mentioned in the previous subsection.

Looking back at how the examples were explored in this subsection, it seems clear that discussions about socio-scientific contexts/issues and applied science have the potential to relate to different aspects of NOS, involving ideas about prediction, consequences, and evidences, and ethical, financial, technological and political perspectives. In the next subsection, specific attention will be paid to whether and how NOS elements were explored in the lessons observed, looking for actual instances and potential opportunities for this type of work.

5.1.4. Talking about science and its nature

Talking about science and its nature, while considered here an important part of school science, was not regularly seen in the lessons observed, which usually focused on scientific content. Nevertheless, these discussions (or not) of NOS elements can be understood more as a continuum than as a clear-cut division between 'without NOS' and 'with NOS', ranging from lessons with no explicit talk about it, to lessons with some remarks (examples) involving these aspects, and finally to lessons largely informed by discussions about it. In these contexts, teachers' diverse ways and levels of talk (or not) about science and its nature mainly included two different, but interconnected, dimensions: epistemic and social-institutional.

The epistemic dimension of NOS encompassed aspects related to the purposes of science and the nature of its knowledge and practices, such as models, variables, evidence, fair-testing, and double-blind investigation. For instance, in his follow up from the fuel choice example, teacher B employed atomic model kits to explain the process of breaking and forming bonds between atoms during the reactions occurring in that experiment, highlighting the differences between them and the actual molecules (and reaction[55]) they were trying to represent:

> Teacher: “Right! **So molecular model kits... the way they work is that we've got different colour beads that represent different atoms.** […] These black beads, when you get to use the model kits, they represent carbon atoms**. The reason why these can only represent carbon atoms is because they've got 4 holes built into it, and that's because carbon atoms can form 4 bonds and they only form 4 bonds**. Ok? The hydrogen are these... so guess how many bonds hydrogen can form... Are you seeing just one hole? Right, it can form one bond. And then the only other atom that you'll need for this bit is the red ones, which represent?”
> Student G: “Oxygen.”
> Teacher: “Brilliant! An oxygen has 2 holes, therefore it can form 2 bonds [...].”
> Student H: “What are the bonds made of?”
> Teacher: “**What bonds are made of? You know in these model kits we are using little sticks? Actually, it's not really a stick, it's like an overlap of the 2 atoms.** So if you imagine this is a hydrogen, and these are hydrogen's electrons, and the electron is like doing this [connects the stick to the bead], another atom of hydrogen will overlap with it and then the electrons will then go around this one as well. So, that's it, they've completed their shells. **So, it's not really a stick like that, it's more of an overlap of 2 circles, ok?**”

Despite this emphasis on these kits not being real representations of the molecules, teacher B did not develop an explicit discussion on the role of models and other forms of representation in science. In this example, the introduction of NOS aspects was thus made <u>implicitly</u>, as a by-product of the activity, without being specifically addressed by the teacher (Fouad et al., 2015), an approach commonly observed when epistemic aspects of NOS (e.g. models, evidence) were involved in these lessons.

Teacher P’s activity on ‘Actions and Consequences’ mentioned earlier is also an example of implicit approach, since when asking students to evaluate ‘facts’ to predict the consequences of an action, no discussion was carried out about the actual meaning of ‘evidence’ and ‘prediction’ in science (e.g. what a scientific evidence is, which types and sources of evidence are employed, how they are obtained, what the relationship between evidence and prediction is). By only asking her students to “use evidence” (from the hand-outs or from their previous knowledge about the topic) to “make predictions”, and not discussing those ideas with them, she created a scenario

[55] Here, they were forming and breaking molecules to illustrate the combustion of methane.

where they worked under an 'anything goes' perspective, generating answers where evidence was not in fact used, but invented by them to make a prediction possible.

On the other hand, <u>explicit</u> approaches were sometimes seen in relation to epistemic aspects. In contrast to teacher B's approach to models in science, teacher K's work around the ideas about Earth and universe examples involved an explicit prompt where students had to write down their own definition for 'model' ("what's a scientific model?") and share their answers with the group. Based on these answers ("a 3D structure", "a plan", "a clone of something", "a type of physical diagram"), she then talked about what a model can be in science and how it can be used to understand what we investigate and to make predictions.

In his exploration of the thalidomide case, teacher F also adopted an explicit approach to important stages of scientific research, prompted by a short video about the main steps of clinical trials:

> Teacher: "**What do you think that [double-blind testing] means?**"
>
> Student I: "A blind person recoded the data."
>
> Teacher: [Laughs] "So, a blind person recorded the data... In a way they're blind, but do you think they're actually blind?"
>
> Students: "No!"
>
> Teacher: "No? What instead are they?"
>
> Student J: "**As in they are not really assessing the person, they're just recording the data, without assessing the person**."
>
> Teacher: "Quite possibly. You could take to that extreme. So they are just recording data, they do not necessarily know what the test is for. Yeah, it's linked to that. [students continue trying to guess] **So, a double-blind test is where the person who is taking the drugs, they don't know whether it's a placebo or not, they might not even know that there's placebo in there, they're just taking the drug. In fact, that's probably what they're told, that they're taking the drug**. And as well as the people taking the drug, the doctors testing it also don't know who's taking the drugs. All right? **That's the double: two levels, two levels of people don't know whether they're taking the drugs or not**. Ok? [...] But that's random. In that way, you keep it all, this thing they kept saying [points to the whiteboard]: fair test or fair trial. Ok? **By making a double-blind, you can accurately tell if the drug works or whether it's placebo effect**. Ok? The placebo effect is when you feel better, but just because your brain is telling you to feel better. All right? [...] So now let's talk about this idea of fair testing or standardization."

It is also worth noting how teacher F's explicit work on epistemic aspects of NOS opened up the debate to its social-institutional dimension, connecting these trials with moral and ethics in research, including animal testing (a student: "what's the difference between a human and an animal life?”), volunteering selection (a student: “why were all the volunteers white?”) and impact on peoples’ lives (students asked about moms suing the company). This approach fostered a view of science as a process of knowledge production, involving not only several stages of research in different levels (e.g. lab testing, animal testing and human testing), but also ethical and social aspects.

This social-institutional dimension of NOS encompassed then aspects related to the connection between science and society (such as ethical and cultural values, and political and financial aspects of science) and to social and institutional work within the scientific world (such as scientific conferences, processes of certification, sharing and accumulation of knowledge).

Elements related to scientific communities were rarely seen in the observed lessons, except for an activity developed by teacher F during his lesson on drug trials named market place. This involved the study of information about one specific drug and the confection of a poster to be presented during a poster session (“like in an academic conference”), where other students had to circulate and ask questions about each other's posters. Similarly, while talking about the example of Darwin’s and Wallace’s works, teacher A also mentioned the importance of exchanges of letters and ideas between them to the further development of the theory of Evolution.

Nevertheless, it is important to remark that these discussions about the social-institutional dimension usually focused more on the implications of science to society (as also seen in the previous subsection) than on social and institutional aspects within the scientific culture. This seems to be linked to an easiness for school science to work on the borders of the scientific world (that is, in-between science and society), without fully entering this world to understand its complex ways of operating. Teacher K’s work on the ideas about Earth and universe, for instance, although explicitly addressing the concept of ‘scientific models’, avoided having an in-depth discussion about why scientists can develop different theories about a phenomenon (e.g. processes of certification, different standpoints, instrumentation) by only stating that “it is difficult to prove a theory”.

Likewise, throughout all her lessons involving Global Warming in the topic of Earth’s atmosphere, teacher P avoided discussing the presence of “contradictory evidences and explanations” in the current debates, focusing on future implications to the planet. Despite mentioning the existence of this contradictory scenario, no further attempt was made to clarify that, which would include discussions about the epistemic (e.g. measurement, instrumentation, evidence) and social-institutional dimensions of science (e.g. certification, negotiation, conflicting explanations), and their connections. Interestingly though was her choice of talking, even if briefly, about these aspects only with her set 1 group, who, according to her, were able to handle these more complex ideas.

Here, it is important to highlight that teaching about this social-institutional dimension of science seemed to be strongly linked to the topics being taught: drug trials, Earth's atmosphere and theory of Evolution offered teachers an easier way to work with this dimension than endo/exothermic reactions or magnetism (topics that seem to more commonly encompass epistemic discussions). As a result, social-institutional aspects of NOS were usually addressed explicitly by the teachers when they were clearly connected with the topics being taught.

In summary, different approaches related to talking about science and its nature were observed during these lessons, not only in terms of which aspects of NOS were being addressed (epistemic and social-institutional), but also how these aspects were introduced into the lesson (implicitly or explicitly) and which scenarios (examples) were employed by the teachers. These diverse forms of discussing NOS then highlight the 'continuum' characteristic behind talking about science in school practices, that is, how NOS can be part of a lesson in different ways and at different depths.

5.1.5. Reflections about the observations

During this phase, science lessons were investigated in relation to examples employed by the teachers, how they interacted with their students, and if and how NOS aspects were being incorporated into these lessons, also looking at the presence or not of intercultural perspectives. Some general trends can be drawn from the main findings presented in the previous subsections. Among these trends, there is the emphasis on scientific content, with less attention paid to explicit talk about NOS. Since learning scientific content is the core aim of the national curriculum, being almost the sole object of assessment in different exams, such as the GCSEs (Ryder & Banner, 2013; Turkenburg-van Diepen, 2013), it seems reasonable that most science teachers dedicated a great part of their work to the teaching of content.

This scenario of curricular and assessment pressures usually favoured lessons involving work on exam questions and use of mathematical skills. The examples chosen by the teachers also seemed to be related to this aim of teaching content and, according to them, this is one of the explanations for their choice of usually addressing their examples illustratively, with fewer instances of contextualised or in-depth work[56]. Since the main goal of the lesson was to teach content, the examples then acquired a merely representative/descriptive usefulness in relation to 'the products of science'.

[56] The examples in table 7 that were classified as 'contextualised' or 'in-depth' are the only instances when these approaches were adopted by the participant teachers during all the observed lessons.

Teacher A highlighted how her use of examples was limited by the curriculum she had to follow:

> Researcher: “Do you think that’s the case?” [after explanation about how teachers usually tend to focus on illustrative approaches towards their examples].
> Teacher A: “That’s the case because **whatever you do as a teacher, you’re judged by your students’ grades**. So you need to think about that all the time. **Expending so much time with those examples and in-depth, it would make a massive difference to what they get at the end**. [...] **We argue all the time, it’s just curriculum, curriculum, curriculum, and if you’re not careful, focusing too much on that is going to mean that you lose the interest of the students**.”

Understandably, this type of school science, heavily bounded to very specific curricular and assessment demands, also affects teaching about the relationship between society and scientific knowledge (socio-scientific contexts and applied science) and NOS, as similarly argued by Hodson (2014a) and Henke and Höttecke (2015). Initially, among all the teachers observed and interviewed there was a consensus about the relevance of introducing aspects of NOS into their lessons, as expressed by teacher K:

> Researcher: “Is this something that you try to do, talking about how science works and the nature of science?”
> Teacher K: “Yes, **I always have how science works in the back of my mind, because I know that when it comes to those kinds of skills, these are the things they need to have for their exams, so things like interpreting, looking at techniques and how people have developed theories.** [...] I really like to get them thinking, because for **me learning is about them experiencing new things and coming up with things, and no me giving them everything**. So I try not to be like that, so **I try to give them more opportunities to ask questions**, to feel comfortable as well to ask questions that they might not ask other people.”

Nevertheless, acknowledging the relevance of NOS to school science and actually teaching about it is clearly mediated by what will be part of official exams. When asked if they teach about NOS, all teachers mentioned the idea of ‘how science works’ as connected to learning specific scientific skills, such as collecting and interpreting data, drawing tables and graphs, carrying out experiments, and sorting out variables. Thus, there seems to be a strong influence on teachers’ own views of what NOS is by what current exams are assessing in relation to scientific skills (usually inquiry skills), as also discussed by Turkenburg-van Diepen (2013) in her research about the ‘How science works’ curriculum in England. For instance, while interviewing teacher P about NOS, our discussion quickly highlighted this view of NOS as inquiry skills that students must learn for their GCSE exams:

> Researcher: “Do you like talking about that [NOS] when you have the opportunity? How is your relationship with that during your lessons?”
>
> Teacher P: “Normally I kind of don’t say how science works; it’s just here in every lesson, you don’t make it very explicit to students that you’re learning how science works when you’re learning about all those things. [...] And then at some point you say **‘alright, do you remember we did that? So, those are the kind of questions you’ll get in your exams. So when we do some practice, we go back and I say ‘do you remember we did that?’.** [...] Because if you think about it, how science works is underpinned in all science we do, yeah? **Let’s say exothermic and endothermic reactions, I can talk about: ‘ok, I’m doing this experiment, so what is my control variable?’.** So, there’s always something.”

This influence of the curriculum and assessment in teachers’ practices was also seen when comparing different cycles and ability groups, where discussions and tasks involving NOS were more commonly seen in KS3 classes and with higher ability groups than in KS4 classes and with lower ability groups. During our interviews, teachers agreed that while the KS3 curriculum (and its lack of an end of stage assessment) offers more freedom for talking about scientific development (including NOS and SSIs), the KS4 cycle hinders their possibilities for more in-depth and diverse (beyond inquiry skills) discussions. In this last case, NOS elements were usually restricted to topics that are officially and explicitly addressed by GCSE questions, such as Global Warming and Stem Cells, as remarked by teachers F (“in the Biology curriculum Stem Cells topic seems to be the only thing where you can put it in”) and A (“it depends on the aspect of the curriculum, the topic, it’s not every topic that gives you that chance”).

Teachers F, P and K also highlighted that not only the existence of an official exam forces them to focus on content with their KS4 students, but also the fact that the KS4 curriculum is so packed that they do not have enough time to have more in-depth and diverse works on NOS. Teacher K, for instance, mentioned:

> Researcher: “Do you feel a difference when you’re talking about these ideas in terms of the curriculum? So, do you feel that you have more freedom to do that in KS3 or KS4?”
>
> Teacher K: “Definitely in KS3. **In KS4, specially the new spec with Biology, it’s just crazy, I don’t have time to teach them to the level I’d love to teach them at**. [...] **That means that next year I’ll have to rush through so much, and that’s such a shame, because there’s such an amazing breadth of things to study and they really enjoy learning about it**, but it’s feels that it’s so much packed into it, that we

don’t have time to teach all of it. **So with most of the teachers it seems to be rushed in KS4.**”

The division of students in ability groups can also impact teachers’ planning, with more emphasis placed on the usefulness of science (applied science) with students from lower ability groups and on more critical and in-depth discussions with high ability students. Teacher B, for instance, only worked on the fuel choice example (the experiment about which fuel was better in terms of energy released during combustion reactions, and an extended NOS discussion about variables, measurement, instrumentation, and economic and environmental behind this process) with his set 1 group, opting to not explore this case with his set 3 students. In this scenario, most teachers felt they could dedicate more time to talk about the examples and NOS with high ability students, whereas with lower ability ones they had to use all their time for content:

Teacher B: “There’s more than one factor [to explain the lack of in-depth and contextualised discussions in science lesson]. **Certainly time is a factor**, if there’s enough time to go into that level of questioning. And it then **comes down to the group you have or the ability of the group** [...]. I think that set 1, traditionally, you’d expect them to be to hold that their interest for a longer period of time. The in-depth questioning, something in that higher order, the high ability students are perhaps better at. **And then with the students at set 3, or who has less ability, sometimes their level of concentration isn’t stronger as the others. [...] You have to try to get your message across in a few minutes**.”

Teacher P: “Some things you try to kind of to make questions accessible to everybody, so open-ended questions for example. **But they are certain questions that you want everybody to get**. Let’s say the example of petrol, ‘why are prices different?’, **for a student working at a lower level, maybe at the point is sufficient for him to know that there’re differences**. Next step for them would be ‘why there are differences’. **But he or she may not be able to think about it right away**, **whereas somebody who is working at a higher level, this ability group will be able to pick up**. Whereas the lower ability might just get the idea that they are different types [of petrol].”

Teachers’ approaches regarding the choice of which NOS aspects were to be taught to different ability groups also seemed to differ. Teacher F, for instance, stated that he usually focused on social-institutional aspects (e.g. funding and ethics) with his lower ability groups and on epistemic aspects with high ability groups, because he believed the latter group to have more conceptual knowledge to understand in-depth and more technical discussions about NOS (e.g. instrumentation and modelling). Conversely, as seen in the extract above, teacher P talked about how she avoided discussions about implications of scientific research to society and other social-institutional aspects with her lower ability students before she was sure they had learnt the official scientific content, otherwise they would not be able to connect these two areas.

Here it is worth noticing that not only external (e.g. curriculum and assessment) and internal (e.g. separation of students in different abilities groups) structures can influence these teachers' practices (Goodson, 2003). According to Goodson (2003), teachers' personal contexts, that is, their own professional identity and biography, including their views about science and science education, can also account for some of their choices while planning and teaching their lessons. During the observation sessions and interviews with the teachers, it became clear that their decisions regarding how they had taught their lessons were connected to their views on the science curriculum, students' achievements and behaviour, as exemplified above by teachers F's and P's different approaches when teaching NOS to different ability groups.

Teachers P and B, for instance, have a more pragmatic view of their students, focusing on ability groups and students' lack of interest in science during our interviews. Furthermore, their original training as Chemists might have influenced their views about science lessons as more connected with carrying out practicals/experiments and developing inquiry skills [a more empiricist orientation towards science education (Tsai, 2007; Mulhall & Gunstone, 2008)]. On the other hand, teachers A, K and F have a less pragmatic and objectivist view of science education, illustrated by their desire to have open discussions with their students, and to take their interests and opinions into account even in lower ability groups.

This is not to say, however, that these teachers have completely different views about science and science education, or even that they hold these views in all their lessons and different classes. The confluence of several other factors, external and internal, can also add to this explanation, and teachers K's and F's work around the cultivating stem Cells example illustrates that: while teacher K (year 10 – KS4 – set 1) focused on debating students' own opinions on the topic, teacher F (year 9 – KS4 – set 2) opted for a task where students had to compare different debates within the scientific community. During our interview, however, teacher F clearly highlighted his preference for having open discussions and for bringing students' views and experiences to the lesson, a position very close to teacher K's own view.

Teachers' diverse perspectives on using examples and talking about NOS was also seen when HOS was introduced as a part of their lessons (notably, only teachers A, K and F occasionally used historical accounts). For instance, in her work on the example of radioactivity research, while presenting Henry Becquerel's investigations under a contextualised perspective, teacher K only cited Ernest Rutherford to name the person responsible for discovering different types of radiation, without any mention to his works.

Like most examples employed during these lessons, HOS was mainly addressed under an illustrative approach, adding to a possible view of science (and scientists and their works) as an end-product of a decontextualised set of activities, as found by other studies in the field (e.g. Allchin, 2004; Höttecke & Silva, 2011; Kelly, 2018). This approach can have an impact on students' own views about science, especially in terms of how science and the scientific community work (Christidou, 2011; Erduran, 2014), a topic that will be further explored in this chapter by RQ2 and RQ3.

This decontextualised and illustrative perspective of school science (and of science itself and its history) can also account for the lack of diversity of examples chosen by the teachers. That is, not only it can affect how the historical examples are being addressed, but also which examples are being addressed. As argued by several authors (e.g. Erduran, 2014; Matthews, 2014c; Sarukkai, 2014; Ideland, 2018; Lee, 2018), modern science is highly dependent on contributions from different communities and people from around the world, both historically and currently. Very few examples discussed by these teachers, however, mirrored this diversity in the production of scientific knowledge, focusing on Western applied knowledge and dedicating little attention to knowledge production by other communities, countries, and local/out-of-school science, as also found by Ideland (2018) in her research with science textbooks in Sweden.

Some exceptions to this trend were teacher K's choice of intercultural examples around ideas about the Earth and universe (Flat Earth, 12 pillars, and Turtle theory) and her approach to different positions on stem cell research; teacher F's lesson on the historical origins of selective breeding in China; and teacher A's discussion about the Evolution theory and Creationism. This use of intercultural examples can be connected with these teachers' professional epistemologies and views of science education addressed above, alluding to their relevant position on the fight against constrained curricula and assessment pressures. In these teachers' cases, it is worth noticing their option to assume a position of 'risk-takers' (Hargreaves, 2003), in which trying a new idea, experimenting with different approaches and teaching in way that they themselves had not been taught is part of their practice, whenever possible. About that, these teachers said:

> Researcher: "Do you do that in other lessons, linking with other cultures?"
> Teacher A: "Yeah, every opportunity I have to link with culture, I'll do it. [...] **That's the thing they remember**. When they come in like to you 10 years later, **those are the things they remember about your lesson**. 'You know what miss? When we talked

about that, when we talked about that?' **Not when you did the calculations that got them their grades, not things like that**. [...] You know what, **they're going to tell other people about that, and they will know how to explain it. They enjoy stuff like that, that's what helps them to remember.**"

Researcher: "Do you usually do that [bringing students' personal experiences and cultures to the lessons] very often?"
Teacher F: "Yeah, definitely. **Because I feel that's how I remember anything**. [...] When I start those conversations, the students, **you see the passion light up in them**. [...] Even if the discussion is almost irrelevant."

Researcher: "You use your questions to connect with something from their culture [...]. Do you often try to do that?"
Teacher K: "I do try to do that, I do try because **I like to know where my students have come from and to make it applicable to them**. Because a lot of time, you know, **they only see scientists of a certain race or a certain sex only, and that's all they see. So I like to open up their minds a little bit**; that's partly why I did the board as well, with the women in science, because I wanted to show them **there's lots of women who do amazing things in science, from different races, different backgrounds, you know, different abilities**. And **hopefully it will inspire them**. [...] **And that's definitely what I like to do, you know, not just give them just one side, one dimension, 'this is how the Western world' sees it. So I try to give them a bigger view**."

It is important to notice that, despite a general lack of diversity of examples chosen by the teachers, they were usually very open to their students' questions related to their interests and out-of-school knowledge. While not usually planning their lessons with diverse and/or in-depth examples, the participant teachers were receptive to their students' out-of-school interests, opinions and examples, as seen in the interactions described in subsection 5.1.2. On the other hand, teachers did not usually initiate these interactions, adopting a question-answer approach more commonly to check students' previous knowledge or understanding of a scientific concept than to try and explore their own ideas, opinions and experiences and incorporate them into the lesson.

In summary, aspects such as curriculum, assessment, ability group, and students' interests were mentioned by participant teachers as important to their practice. It then became clear that any lesson plan to be developed and implemented requires the consideration of different external (especially curriculum), internal, and personal (e.g. teachers' identities and preferences) factors, all which will be important to the Implementation phase in this project.

5.1.6. Final thoughts and implications for the Implementation phase

The aim of this section was to explore science teachers' practices around HOS, NOS and intercultural aspects of Science, addressing RQ1: "What are the possibilities and obstacles found in teachers' practices and realities for the inclusion of intercultural aspects of science into school science?". In order to answer this question, this investigation focused on the following aspects: the examples (including HOS) these teachers were using to teach scientific topics; how they were using these examples; how they were engaging and gathering participation from their students; if and how discussions about NOS and SSIs were being incorporated into their lessons.

But more than just describing these school science practices (through the analysis of lesson observations), my goal was to understand these practices as multi-layered, that is, as impacted by structural (e.g. KS3 versus KS4 curricula) and agential (e.g. teaching preferences and views about different ability groups) aspects. In this scenario, the use of CR perspectives, as argued in chapters 3 and 4, helped me to explore these teachers' practices beyond the simple description of different approaches employed in relation to examples, NOS, HOS and diversity in science. By connecting these observations with their own explanations for choices made in the context of their teaching, and with other literature in the field of (Science) Education, I hope to have built a certain degree of understanding about the complexity behind these realities that can be helpful for my subsequent analysis of RQ2 and RQ3 and for the planning of the Implementation phase.

For instance, in relation to the examples and how they were employed by the teachers, it is worth noticing the weight they put on bringing cases and items from everyday life to the scientific topic being taught, highlighting their concern with connecting science to students' own realities. Nevertheless, several factors (e.g. curriculum and assessment, ability groups) seem to constrain the possibilities these teachers have to carry out contextualised and in-depth discussions about these examples. Thus, they apparently lack the time to move from an illustrative perspective towards moments of contextualised and critical discussions about these examples.

The possible effects of this focus on illustrative approaches in opposition to contextualised/in-depth ones will be further discussed in the following sections of this chapter, which will look into students' views about scientists and NOS. In addition, the possibilities of the intercultural model of HOS to the promotion of more contextualised and in-depth discussions about examples explored in science lessons will be a significant feature of the TLPs developed and implemented as part of the Implementation phase. Lessons learned from these participant teachers' uses of examples will then ground the choice and exploration of examples in these resources, especially in relation to the importance of balancing teaching of content and more contextualised/in-depth approaches to these examples.

Constraints brought by external and internal factors can also explain, at least partially, how teachers interacted with their students. Teachers usually tried to engage their students through constant questioning, indicating a generally constructivist tendency regarding contributions to the lessons. The content of these contributions, however, needs further reflection: while there were moments of asking for students' own views and ideas about a topic, most of these exchanges between teacher and students focused on covering their knowledge about a scientific concept. While students were encouraged to contribute to the lessons, teachers tended to direct these contributions to guarantee the covering of scientific content part of the official curriculum and exams.

In this scenario, more focus was placed on inquiry skills (such as collecting data, carrying out experiments, sorting out variables, but without any reflection about these processes), than on explicit discussions about other epistemic and social-institutional aspects of science. With the main aim of teaching scientific concepts for summative assessment, especially in the case of KS4 groups, talks about NOS and SSIs were very often seen as only a by-product of the lessons, being the centre of attention only in some very specific topics, such as Stem Cells or Earth's Atmosphere.

Nevertheless, these findings related to teachers' interactions with their students are still relevant to the Implementation phase: even if often focusing on content learning, these teachers' openness to interacting with their students' knowledge, views and ideas can be useful as a pedagogical strategy for the planning and teaching of the TLPs. NOS teaching and learning benefits from more dialogic and open discussions about scientific work and the scientific community, so if teachers are offered the chance to plan and try out a more diverse set of conversations which are still built on their normal practice, then the exploration of NOS aspects in their lessons can be carried out more naturally (i.e. based on a pedagogical strategy that is familiar to them).

In summary, it became clear during this investigation that while most teachers are usually interested in having more in-depth and open science lessons, their planned and implemented lessons are not necessarily like that. Hence, and returning to my original research question, the results from this exploratory study have shown that very few teachers actually incorporate meaningful discussions and tasks about NOS or take intercultural perspectives into their lessons. Examples employed and activities proposed were still very connected to a view of scientific knowledge as solely a 'product', with no reflection about its socio-cultural and intercultural origins.

Apart from personal views about science education (Goodson, 2003) and the lack of freedom for teachers to take risks (Hargreaves, 2003; Ryder & Banner, 2013), this can also be linked to the lack of teaching resources that include these more diverse examples and in-depth approaches. During this study, three out of five participant teachers emphasised their interest in teaching with more diverse examples about scientific work, especially to motivate their students and “open-up their minds”. Nevertheless, they also mentioned the difficulties to develop and implement different lessons within the curricular and accountability constraints they regularly face, as exemplified by teacher A:

> Teacher A: “It’s just the amount of workload: you’re either marking, planning lessons, doing this, doing that. **So, it just makes that time less and less available for you to say ‘I want to dedicate time to find things like that’**. While if we said in lesson planning that we’re gonna put those things in our lesson, maybe one topic that is relevant and things like that, **then it wouldn’t be a too massive search in one time, it wouldn’t be too much**.”

The need for working with diverse examples and discussions about NOS along with the official science curriculum is clear, as also argued by several authors (e.g. Erduran; 2014; Clough, 2018; Ideland, 2018). This is not, however, an impossible task, as shown by some lessons taught by these teachers. As mentioned above, findings from this Exploratory phase were employed as an important source of reflection for the development of the Implementation phase, which tried to balance both effective teaching of content and open discussions about NOS within the time available. Another important implication from these findings was the possibility of working with the KS3 curriculum, which seemed to be more open and to offer a certain degree of freedom to teachers to develop more creative and diverse lessons, as compared with the KS4 curriculum. In addition, it became clear during this study that, despite curricular constraints and the pressure of assessment, teachers are open to having dialogic types of interaction with their students, a practice that is regarded as widely applicable to teaching about NOS (Clough, 2006; 2011; Allchin, 2014), and that will also be an important feature of the Implementation phase.

5.2. Different people in different places: students' knowledge about HOS[57]

The goal of this section is to present and analyse data generated by the HOS questionnaire, observations and follow-up interviews carried out with participant students and teachers to address RQ2: "In which ways are participant students aware of the history of scientific development carried out by different people in different places of the world? What can be influencing and shaping their awareness?".

This study then aimed at depicting students' knowledge about HOS, with special attention to what they know about science being done by people and communities from different parts of the world, and how this knowledge is constructed through their engagement with school science. As discussed in chapter 4, this stage involved an initial exploration of students' knowledge about HOS through an open-ended questionnaire. This was then followed by interviews and complemented by findings related to RQ1, aiming at reflecting upon how these views are built from a multi-layered perspective about the realities of school science (e.g. their teachers' practices, the curriculum and examinations adopted at school A).

The main findings from this stage will be presented in subsection 5.2.1 ('Students' knowledge about scientists and countries in science') and further explored in subsections 5.2.2 ('Knowing scientists versus Knowing about scientists') and 5.2.3 ('Representativeness in Science and its ramifications for school Science') in connection to the interviews and observations. Lastly, in subsection 5.2.4 I will discuss some implications of these findings for the Implementation phase.

5.2.1. Students' knowledge about scientists and countries in science

Figures 6 and 7 (respectively, school A and school B) display students' answers to Q1, Q2 and Q3 from the HOS questionnaire (see chapter 4 for the instrument). At both schools, most students (95% at A and 98% at B) cited at least one scientist when asked about specific names.

[57] Findings and discussions related to this section (RQ2) have been previously published as part of two journal articles (Gandolfi, 2018a; Gandolfi, 2018b).

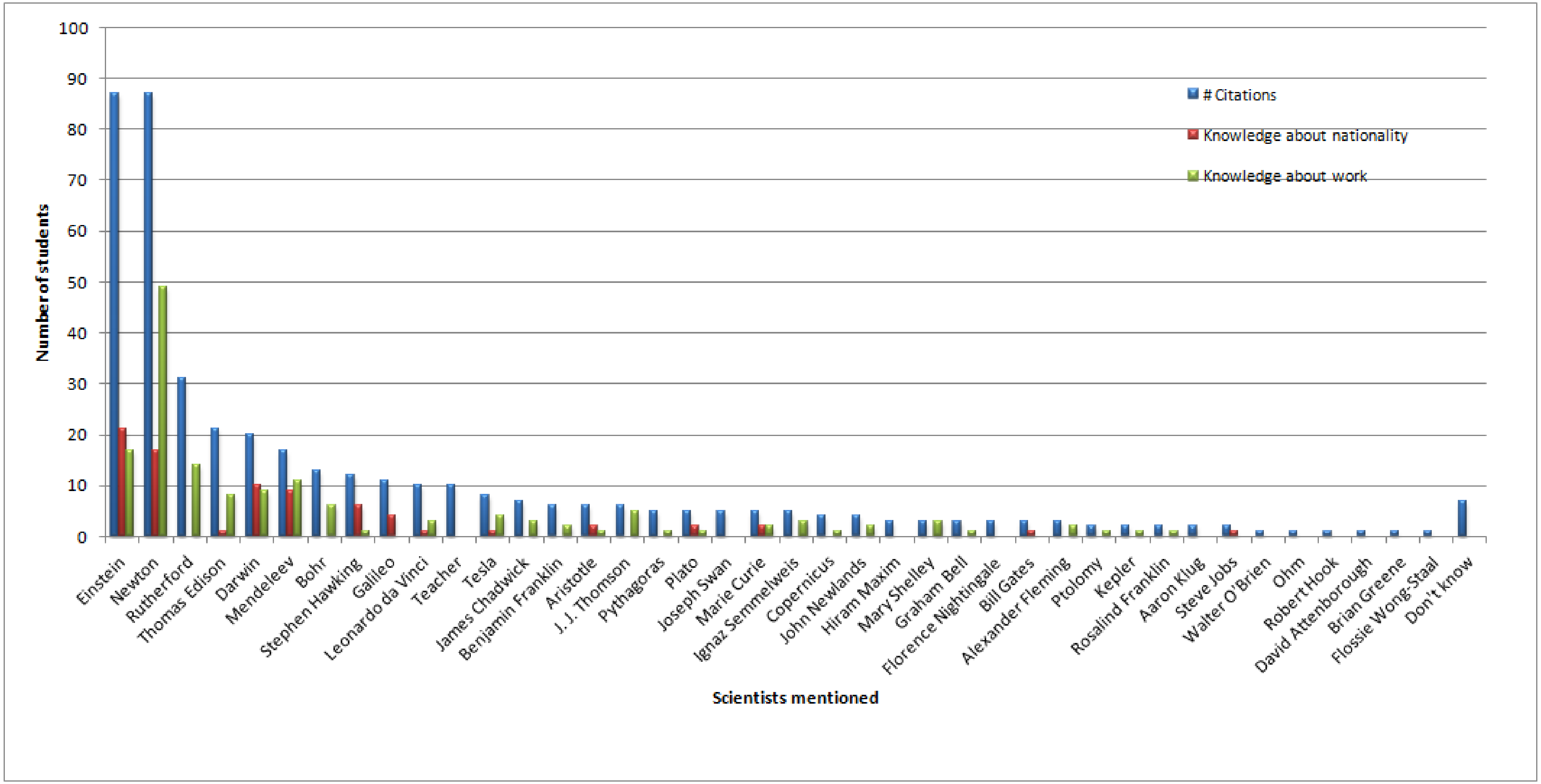

Figure 6. Scientists mentioned by students from school A (Q1+Q2+Q3) (n = 135)

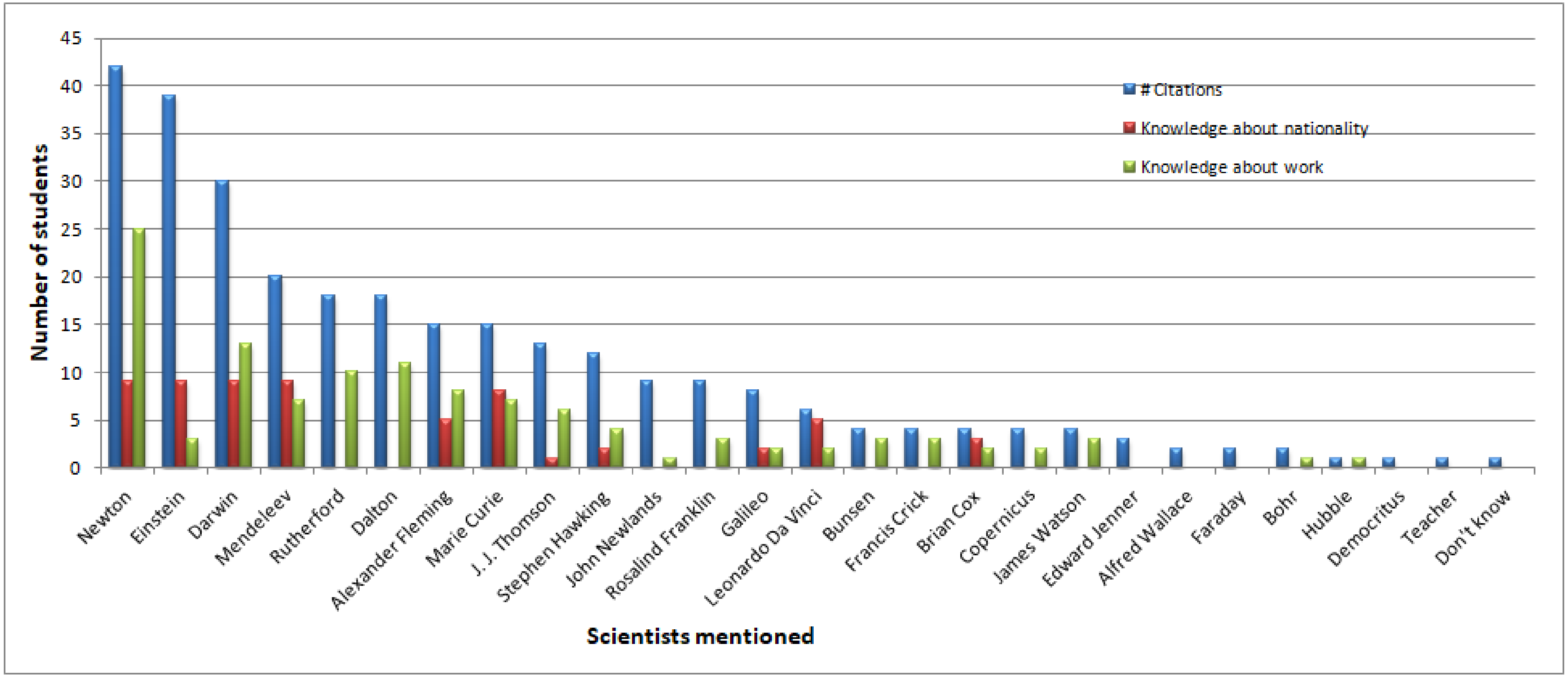

Figure 7. Scientists mentioned by students from school B (Q1+Q2+Q3) (n = 65)

In school A, Einstein, Newton and Rutherford received the largest number of mentions (64%, 64% and 23%, respectively). Most of the 135 students at this school, however, were not able to name these scientists' contributions to science: among the students who knew some scientists' names, most of them only knew that and did not possess any specific knowledge about who those scientists were/are as individuals (also seen in their responses to the question about nationality) and as professionals.

Meanwhile, in school B, Newton, Einstein and Darwin appeared at the top of the students' list (65%, 60% and 46%, respectively), and, in comparison to the results of school A, we can observe that a proportionally larger number of students was able to provide more information about these scientists, mainly in terms of their contributions to science. There was still, however, a great difference between citing the names of scientists (Q1) and actually knowing about their origins (Q2) and work (Q3).

In both schools, there is a clear influence of the subject being studied by these students immediately before or at the time of this research. For instance, one group at school A (year 8) cited several examples connected to the topic of Solar System (such as Copernicus, Plato and Aristotle), which had been taught by their science teacher two weeks before the application of the HOS questionnaire, in contrast to other participants who generally did not mention these names. Similarly, at school B, Alexander Fleming was the second most mentioned by students in year 9, who had learnt about him some weeks before this questionnaire was applied; meanwhile, he was less remembered by students in the other groups. It is important to remark, however, that the participants in years 9 and 10 of school A and in year 10 of school B had previously learnt these topics, which means they must have heard about Copernicus, Plato, Aristotle (school A) and Fleming (school B) before. Furthermore, these results show that having recently heard about these scientists did not necessarily lead to more connections between them and their work.

Figures 8 and 9 (respectively, school A and school B) display students' answers to Q4 and Q5. When specifically asked about countries' contributions to contemporary science, the number of responses was high at both schools (86% and 75% at school A and at school B, respectively). It is worth noting that these answers were generally related to countries that could be easily connected to any dominant position in the world, not only in science, such as the USA (62% of students at school A and 58% at school B) and the UK (49% of students at school A and 48% at school B).

The question related to countries/civilizations in science in the past received the lowest number of responses: 34% (school A) and 31% (school B) of participants did not know how to answer it. Among those cited by the students are: UK (35% at both A and B), USA (23% at A and 42% at B), Germany (17% at school A), Russia/USSR (15% at A and 9% at B) and Greece (13% and 9% at A and B, respectively).

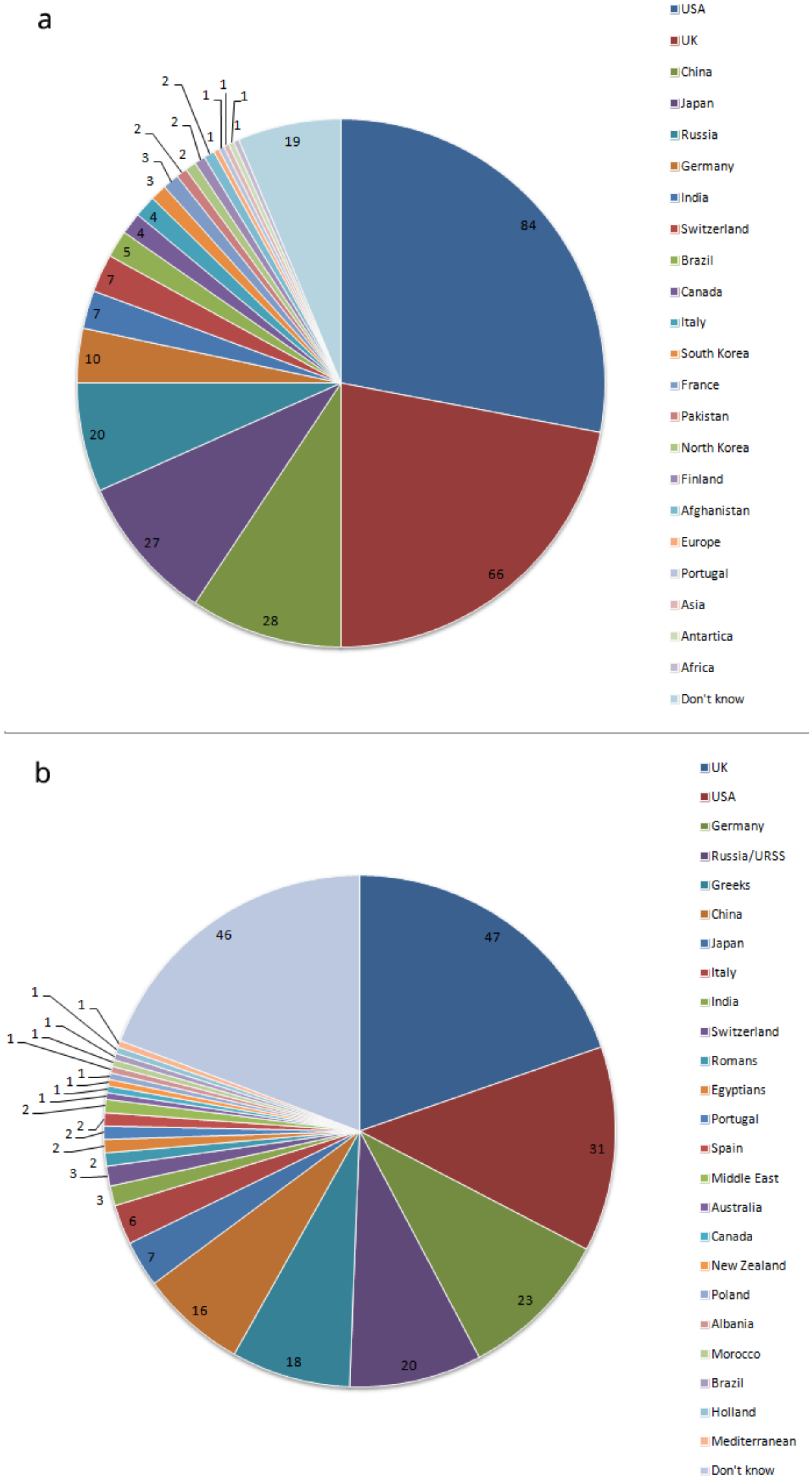

Figure 8. Countries mentioned by students from school A; (a): countries nowadays (Q4); (b): countries in the past (Q5) (n = 135)

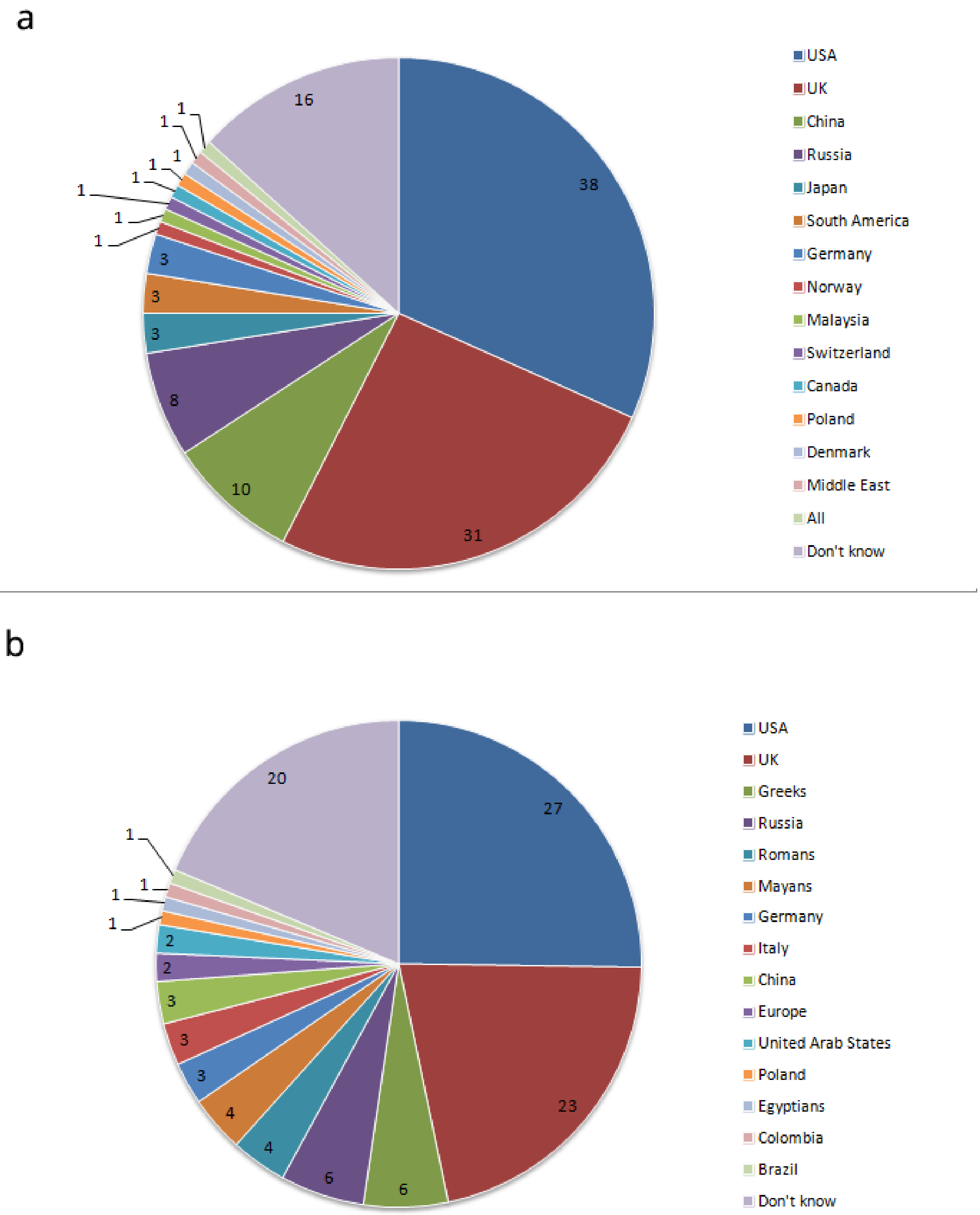

Figure 9. Countries mentioned by students from school B; (a): countries nowadays (Q4); (b): countries in the past (Q5) (n = 65)

Q6, the last in this instrument, was used to encourage students to consider more diverse answers. As a result, 30 students (15% overall) elaborated on their original answers about countries in science, but they mostly cited other western societies (such as France, Canada or Switzerland) that had little to do with their own cultural background or any underrepresented group. Among those who talked about science being done by communities closer to their cultural background[58], there were: an African boy who cited the Egyptians; a Lithuanian girl who talked about checking out Lithuanian science webpages to search about scientific work being done there; a Chinese boy who talked about China's work on solar power; a girl with Iraqi origins who learned about Persians' and Arabs' historical contributions to science from her family; and a boy with Iraqi background who had read a book about the historical works carried out in the country on the circulatory system and heart surgery.

An initial analysis of these results reveals relevant trends regarding students' knowledge about scientists and countries in science. First, there seems to be a disconnection between knowing the name of scientists and actually knowing about their work and lives. More specifically, whereas most students were able to cite at least one scientist, they were generally unaware of these scientists' origins and/or contributions to science. This contrast was further explored during the interviews with students and their teachers, and through the results from observations of their science lessons. These findings, including participants' own reflections about this scenario, are presented in subsection 5.2.2 ('Knowing scientists versus Knowing about scientists').

Another trend arising from these initial results is related to which scientists and countries are deemed as relevant to science: a qualitative analysis of these names hints to the lack of knowledge about scientists from different backgrounds (race, ethnicity and gender) and about different countries' contributions to science. These findings point to the issue of representativeness in historical and contemporary accounts about the scientific world, which was also investigated during the interviews and lesson observations and will be discussed in subsection 5.2.3 ('Representativeness in Science and its ramifications for school Science').

5.2.2. Knowing scientists versus Knowing about scientists

Students' answers about scientists, their origins and work revealed that most named people involved with science without knowing much about these people and their contributions to scientific research. This result raises a question about how young

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[58] The relationship between students' answers to Q6 and their cultural background was established through a self-identification process (see appendix 2).

people learn about scientists' stories through school science and mass media. Although it should be recognised that asking students to name scientists can influence the type of recollections they will have to make (in terms of images of these scientists), there is a superficial status of students' knowledge that can be at least partially explained by an illustrative use of HOS and accounts of contemporary science (Allchin, 2004; Höttecke & Silva, 2011; Gandolfi, 2017).

This illustrative approach, as discussed in the previous section, can be understood as a superficial mention of a scientist merely as a representative of the topic being taught, without any further discussion about her work and life, or about the social and historical contexts involved in this work. In the school scenario, this can be exemplified by citing Newton as the discoverer of gravity or Dalton as the one responsible for one atomic model, as seen during some of the observed lessons. In the case of mass media (e.g. internet, movies, cartoons, and TV programmes), this approach usually appears in anecdotal and stereotypical representations of scientists, with no discussions about their actual work, histories and contexts (Christidou, 2011; Ideland, 2018).

The traditional image of Albert Einstein and his association with the $E=m.c^2$ equation is an example of the power that mass media has in circulating names and images of scientists (Gurgel et al., 2014). This can help explain why Einstein was cited by most students at both schools (64% and 60% overall at schools A and B, respectively), similar to results obtained by Gurgel and others (2014), even though his theories are not discussed in secondary school science in England. Furthermore, the fact that only 16% of these students knew about his contributions to science highlights the impact of illustrative accounts about scientists on students' actual knowledge about their work.

During the follow up interviews with these students, it became clear that they knew about Einstein (and Stephen Hawking) mainly from the mass media. Students from all nine investigated classes stated that they had learnt about these scientists outside school, and that they were also part of the 'pop culture': "everybody knows who he [Einstein] is, because he was the smartest guy in the world"[59]. Furthermore, among the 38 students interviewed, only eight of them remembered Einstein's or Hawking's works, confirming the results obtained with the questionnaire regarding the disconnection between knowing these scientists and actually knowing about their contributions to science. When asked why this was the case, students commented that most of these mass media sources usually concentrate their discussions on anecdotal biographical information, such as Einstein not being good in mathematics, not liking school or having dyslexia.

[59] Year 9 – set 2 – School A

In the case of the other scientists cited, the interviewed students stated that the main source of their knowledge about them was their science lessons, highlighting the relevance of school science practices on what students know about scientists. And in the lessons observed during this phase, HOS was mainly employed by the teachers through an illustrative approach, without a contextualised/in-depth discussion about their actual work. In her lesson on Radioactivity, for instance, while citing Ernest Rutherford as the discoverer of the alpha, beta and gamma rays, teacher K did not discuss this process of discovery, nor who this scientist was.

Still, by having at least heard a scientist's name and work during a science lesson (e.g. Rutherford and radioactivity), students should be able to answer the question about one's contributions to science without any problem; the lack of context and life story should only impact their answers about this scientist's origins. Nevertheless, it can be argued that it is exactly this lack of in-depth/contextual analysis work that hinders students' knowledge about scientists' contributions to science, as evidenced by the already mentioned cases of older students not remembering examples they had learnt in previous years. That is, without the connection between a scientist and the context of her scientific work, students could hardly build any kind of long-term association between names and achievements, only remembering concepts and scientists separately, without connecting them in a larger context of scientific development.

Both teachers and students agreed, during our interviews, that little time was spent during science lessons to studying and understanding these scientists' contexts and works, with more emphasis placed on connecting names to general ideas. Different students explained why they did not remember what these scientists had done or where they had come from:

> Student A[60]: "It's like **briefly mentioned**, they don't go into like details, they just tell us what the person did and who the person is. **They don't go into detail about like what they actually researched**."
>
> Student B[61]: "[...] And also in the lesson sir **doesn't talk about in detail**, he just talks about their names."
>
> Student C[62]: "**We only know their names, we've never learned about what they did or where they came from**. [...] Yeah, we just hear that he [Newton] was hit in the head with an apple and that's it."

[60] Year 9 – set 2 – School A

[61] Year 8 – mixed – School A

[62] Year 9 – set 1 – School A

There were, however, situations in which teachers adopted a contextualised/in-depth approach towards HOS. For instance, during the same lesson on Radioactivity at school B, teacher K also talked about Marie Curie's contributions to the topic, and discussed her life and work with her students, with the aid of a video narrating her personal and professional life. This video helped the teacher discuss her life history and main achievements as a researcher and the relevance of her research to society at the time. Interestingly, students from both schools who cited Marie Curie (Q1) had a very good knowledge about her work (Q2) and origins (Q3) in comparison to other scientists. This can be related to the special place Marie Curie occupies in school science as one of the few female scientists acknowledged by HOS, with usually more time dedicated to discussions about her life and work.

The choice between an illustrative or contextualised/in-depth approach can also explain, at least partially, the differences found in Q2 and Q3 when comparing schools A and B. While students from both schools presented a generally disconnected knowledge about scientists and their works and lives, those from school B answered Q2 and Q3 more completely than those from school A. Based on the lessons observed, this can be related to a greater dedication of teachers at school B (teachers A and K) to more contextualised discussions about HOS than teachers at school A (teachers B, F and P): teachers at school B tended to use this approach when introducing a historical case (as seen by teacher's K lesson on Marie Curie) more than teachers at school A, where only teacher F was observed doing something similar in his lessons (as seen in the lesson about the Thalidomide case with his year 8 group).

During the interviews, teachers from school A stated that they do not address aspects of HOS and/or names of specific scientists very often in their lessons. And, when they do it, it is usually through an illustrative approach to quickly connect the name of the scientist with the scientific concept they are teaching, because some exams can directly ask students those questions (about Darwin, Ignaz Semmelweis and Mendeleev, for instance). In this scenario, these teachers made it clear that, especially in the case of KS4 groups, they only mention scientists that are officially part of exam specifications:

> Researcher: "Do you think the way you work with the example changes?" [after talking about illustrative and in-depth approaches and the differences in KS3 and KS4].
> Teacher F: "That's definitely true. And I think that, in a perfect world, you'd have the same amount of time for both [KS3 and KS4 groups], but the difference is that **the amount of content in KS4 is so much higher that is a far more sort of like descriptive process of 'this is everything you need to know; I'm gonna give you this example because you need to know this example'**. Whereas in KS3, I tell them

about the twin study and things, that **it isn't come up in the test, but I know it makes really interesting learning** about that as a lesson objective."

It is important then to highlight that the introduction of HOS into science teaching is not simply a matter of choice based solely on teachers' views about school science, but it is in fact connected to what they feel they need to teach in terms of the curriculum, as also found by Höttecke and Silva (2011). As discussed in the previous section, teachers constantly dedicated most of their lessons to the teaching of specific concepts, with less attention paid to scientific skills, HOS or thinking about NOS, arguing that the former are almost the sole object of assessment in official exams.

This could also explain their choice of usually addressing historical examples under an illustrative approach, with fewer situations where contextualised/in-depth work was carried out. Similar to Höttecke and Silva (2011)'s findings, teacher A highlighted that the freedom to have more in-depth/contextualised discussions with students quickly disappears with the pressures and time constraints presented by the KS4 curriculum and accountability, as quoted in the previous section: "Expending so much time with those examples and in-depth, it would make a massive difference to what they get at the end. So you would really love to expend so much time to go in-depth into what the examples tell and things like it. [...] But if it's gonna mean that you won't have enough time to teach what your content is."

In this case, HOS can acquire a merely representative/descriptive usefulness, hinting at an approach to school science more as teaching about the products of science than about how science works to develop these products. Here I agree with Forato and others (2015), Erduran (2014) and Ideland (2018), who argued that there is a danger in bringing HOS into science lessons as only an illustration (that is, emptied from its original context), because it can promote a naïve view of the scientific endeavour, where HOS is only another memory-based practice developed throughout the lesson. These reflections are closely connected with what Allchin (2003; 2004) called 'Pseudohistory', an approach to history that "uses facts selectively and so fosters misleading images" (Allchin, 2004, p. 179) and involves a lack of respect for historical context (Whiggism).

Several authors (e.g. Wang & Marsh, 2002; Allchin, 2004; Clough, 2011) have also argued about the extent to which this decontextualised (illustrative) approach to HOS, with the sole mention of names and anecdotes, should be considered satisfactory when advocating the introduction of HOS into school science. Contextualised/in-depth historical cases can do more for school science than the teaching of a "comprehensive 'greatest hits' survey course" (Allchin, 2004, p. 192), an approach that, according to the findings from this research, has clearly little impact on what students really know about science and scientists. A question that remains, however, is how to address teachers' concerns about official curricula and assessment while still promoting this contextualised approach to HOS in secondary school science, an issue that I have explored during my Implementation phase, and that I will further discuss in chapters 6 and 7.

5.2.3. Representativeness in science and its ramifications for school science

The issue of stereotypical images of scientists and their impact on students' ideas about who can participate in scientific research has been discussed by several authors in the Science Education field. That is the case, for instance, of different research on how school science portrays scientists and their work, most with the goal of understanding students' engagement with science and with scientific careers (e.g. Buck et al., 2008; Archer et al., 2010; 2012; Christidou, 2011; DeWitt et al., 2011; Christidou et al., 2016; Kelly, 2018).

These studies highlight problems with stereotypical images and representativeness in science, constructed and perpetuated both by mass media and school, as briefly discussed in the previous subsection. Stereotypical views of scientists usually involve images of male, white and eccentric persons, summarised by the popular figure of Einstein (Buck et al., 2008; Christidou, 2011). According to Kessels and others (2006, p. 764), this image "reflects cultural beliefs within a given society" and is influenced by judgmental frameworks that attribute particular features or skills (doing science) to specific social groups (usually white, male, eccentric, genius), as also more recently argued by Ideland (2018).

These popular images can influence students' notions of the type of people scientists are or must be, possibly creating discontinuities between this 'scientific identity' and their own personal identities, as found by different studies (Cleaves, 2005; Hazari et al., 2010; Archer et al., 2010; Christidou, 2011; Christidou et al., 2016). One can argue that this 'scientific identity' disseminated to young people can be at least partially linked to representativeness in science, helping to create a vicious circle where the lack of diverse representations discourages people from different backgrounds getting into the field.

Results from this research show that this issue of representativeness in school science continues to be relevant, especially in terms of gender and cultural backgrounds. Taking into account the scientists cited by the students in Q1, there is a lack of knowledge about women (except for from Marie Curie and Rosalind Franklin) and about people from minority groups (non-European and not from the USA) in science. Girls from year 10 at school B realised, while working on the questionnaire, that they did not know almost any scientists from minority groups. These girls in a high ability class (with about 60% of black students and 25% from other ethnical minority groups) were shocked to conclude that they were only talking about white European men in science, with very few female and minority group examples coming to their minds:

> Student D: "Sometimes we don't even learn about them [scientists from other backgrounds or gender], **even if they do make that discovery, whenever we are taught in the classroom, they don't deem them as significant enough to go and teach it to us**. And it's really really sad, because you see all these European people and you kind of wonder if you're not from a European country, '**did anyone from Asia, did anyone from Africa do anything to go and contribute to science?**'"

This situation is very similar to findings by Archer and others (2012, p. 981) during their study on girls' attitudes towards science. While very interested and engaged with it, these girls presented a tacit alignment with masculine views of science: "it was notable that many of the girls we interviewed identified male (rather than female) scientific role models". Additionally, the same research group (Archer et al., 2010, p. 635) pointed out that this was not only a girls' view of science, but in fact boys shared this masculine image of scientific work: "the boys argued that boys are better at science, explaining that the scientists they know are all male".

This highlights the impact of school science on students' perceptions about science and, more importantly, the position of schools as reproducers of social norms and traditions, such as of a white, male, upper class scientific identity (Ideland, 2018). A group of students from school A (year 9 – set 2), for instance, talked about that when explaining why they had never heard about scientists from different backgrounds or genders:

> Student E: "It's because of History. Because back then, **women didn't have any rights, black people most of times were slaves, and stuff like that**. [...] If you look around, there has only been... like **black people have only been good in History, like Nelson Mandela and stuff like that**."
>
> Student F: "I just feel like it's not brought up because we live in like a diverse world, but we don't accept it. And **we don't acknowledge people that are other than white or other gender**."
>
> Student G: "Or sometimes they don't even say on TV. They just say it when it's probably too late. Or if they do say it, **they don't say it in the way they say it about the white men**. They only talk about the great things they did, and sometimes **it makes you wonder 'what about the other people?'. They don't represent the other people in the way they represent white men**."

Two main explanations were given by the students to their lack of knowledge about diverse scientists: historical reasons and contemporary issues. In the first case, students highlighted a historical lack of equity in terms of rights and opportunities ("being in the right place at the right time") in non-European countries and for women (see student E's quote above). They also talked about the absence of education, resources and interest to carry out scientific research in non-mainstream communities the past:

> Student H[63]: "Maybe society thinks that, you know, the mainstream countries **maybe have more education than other countries**."
> Student I[64]: "Maybe they **[mainstream countries] valued science more than other civilisations**. [...] I'm not saying that others didn't. But like they valued it more maybe."

On the other hand, some students focused their explanations on the fact that nowadays we only talk/learn about male western scientists because they are the ones who are popular, being responsible for big discoveries; they also talked about how we do not acknowledge diversity, including discussions about racism and distrust in science being done by 'outsiders':

> Student J[65]: "I think that's because **men were more accepted**, like their breakthroughs were more talked about than women's**. Women aren't really as known by their discoveries**. **Maybe that's why they're not really as talked about.**"
> Student K[66]: "I think that's because **men had more opportunities to make like big discoveries than women did, and big discoveries are really the only important ones**."
> Student L[67]: "Maybe at the time when these discoveries were made it was mainly the Caucasian race, the people that were in charge of that, were doing that. **Anyone else that was doing it was seen as, maybe their work was discarded, or people thought it wasn't right**."

If we also analyse their answers to Q4, Q5 and Q6, we again observe this lack of diversity regarding cultural backgrounds. Similar to the results obtained by Gurgel and others (2014), students in this study focused their answers on countries that currently dominate the world's economy and production systems (USA, UK, China, Russia, Japan). This can be linked to a predominant image of science as connected to

[63] Year 8 – mixed – School A
[64] Year 8 – mixed – School A
[65] Year 8 – set 2 – School B
[66] Year 8 – set 2 – School B
[67] Year 10 – set 1 – School A

power and resources, but having little to do with exchanges and collaborations, as discussed by Miller and others (2006) and Hazari and others (2010). This explanation was indeed seen during our interviews, when students attributed their choices of countries to ownership of technology, money and power, and access to education and communication.

The lack of diversity in terms of gender and cultural backgrounds in students' responses is very relevant to school science and research in Science Education, since it illustrates the absence of knowledge about science as an intercultural community, with its own history of exchanges and contributions made by different people in different parts of the world (Hazari, et al., 2010; Fan, 2012). Since, as mentioned in the previous section, very few examples employed by the teachers involved diversity in the production of scientific knowledge, these findings indicate the need for reflection about the place of HOS in teachers' practices and about which type of HOS is being included in school science.

According to several researchers (Allchin et al., 2014; Erduran, 2014; Sarukkai, 2014; Ideland, 2018), this 'selection bias' towards historical and contemporary narratives about science can impact students' perceptions of scientific identity, a view also shared by some participant students in this research:

> Student M[68]: "I feel that sometimes **people might be like feeling down because of other scientists, because if they are not represented in the world like these [mainstream] scientists do**, then they might give up on their dreams of being [a scientist]."
>
> Student N[69]: "I guess this [lack of diversity in science] might be a problem, because it goes to show, it might **spread the wrong message that everyone else can't really make scientific discoveries**."
>
> Student O[70]: "Yeah [it's a problem], because it **may not empower them to go into science if they think that their work isn't going to be accepted and listen[ed] to**."

As also discussed in the last subsection, curriculum constraints and assessment pressures cannot be forgotten when analysing teachers' practices regarding representativeness. In the lessons observed, the focus on conceptual knowledge and illustrative accounts of scientific development seemed to be connected to a reality of school science where the time available for the work with culturally diverse resources is very restricted.

[68] Year 9 – set 2 – School A

[69] Year 10 – set 1 – School A

[70] Year 10 – set 1 – School A

Another important constraint to teachers' practices is that most of the teaching resources available, even those coming from a historical perspective, still do not take into account the debates about representativeness in Science (Dennick, 1992; Hodson, 1998; Erduran, 2014; Ideland, 2018), as discussed in chapter 2. As identified after a brief analysis of the textbooks and materials used by these teachers, very few examples involved contributions from different cultures or people to science, with some exceptions like Marie Curie, and different views on the origins of the universe and the Earth. Interestingly, these specific scenarios were all incorporated by the teachers into their lessons, alluding to the positive effects of making culturally diverse accounts about science available.

In summary, when advocating the introduction of HOS into regular school science, the important point of who will be part of the narrative and which examples (countries/cultures/civilisations) are going to be employed needs to be considered. Once again, however, the question of how to work with science curricula that are traditionally non-diverse and with large-scale examinations that do not address these issues still remains. Even if changes in practices are acknowledged as necessary, the possibilities to do so are still very constrained by the field of Science Education itself, with its long-term association with non-diverse views of the history of scientific development.

5.2.4. Final thoughts and implications for the Implementation phase

The aim of this section was to investigate students' knowledge about HOS, focusing on what they knew about science being done by people and communities from different parts of the world, and whether this knowledge was related or not to science lessons and teaching using HOS, as illustrated by RQ2: "In which ways are participant students aware of the history of scientific development carried out by different people in different places of the world? What can be influencing and shaping their awareness?".

While the limitations of this study need to be acknowledged (e.g. employing a memory-based survey about scientists and countries, and the small sample of participants), the combination of an open-ended questionnaire with observations and interviews, inspired by a multi-layered (CR) perspective, allowed me to explore how the complex realities of school science can influence students' knowledge about HOS. This collective analysis wielded results similar to other investigations about representativeness in school science (e.g. Archer, et al., 2010; Archer, et al., 2012; Gurgel, et al., 2014) and the illustrative use of HOS (e.g. Allchin, 2004; Höttecke & Silva, 2011; Forato et al., 2015).

The decision to use a memory-based questionnaire as a starting point for this research has its drawbacks, especially in relation to the several different ways HOS can be discussed during a science lesson; that is, by having used a very specific instrument, this study might have prevented some students from expressing their knowledge about HOS in a different way that was not covered here. Nevertheless, during the interviews, they had the opportunity to talk more about science and scientists, overcoming at least partially some of the shortcomings related to using only surveys to investigate people's knowledge and views about a topic.

It is also worth noting that, although not explicitly discussed in the previous subsections, some characteristics of students' historical knowledge (i.e. their understanding about history and their perception of historical timelines) can also impact their answers. For instance, when asked about countries that were relevant to science in the past, these participants concentrated their answers in a not so distant past, mentioning places like Germany, the USA and the USSR (that is, countries that can be considered historically still very young). Here, it seems clear that students' understandings of what 'past' means can influence how they engage with historical accounts, and the importance of contextualised and in-depth approaches to HOS, with attention to the contexts of knowledge of production, becomes even more apparent.

Going back to my RQ2, the main findings from this research stage have shown how secondary students still hold a narrow view about scientists, not only in relation to their work (knowing scientists versus knowing about scientists), but also about who they are (representativeness in Science). Furthermore, they also perceive science as concentrated in very few and dominant countries, which are seen as the only ones possessing the necessary features to foster relevant scientific development, in opposition to the rest (and majority) of the world.

As discussed by other researchers (Buck et al., 2008; Archer et al., 2010; 2012; Christidou, 2011; DeWitt et al., 2011; Christidou et al., 2016), diverse role models (gender, race and cultural backgrounds) and contextualised and real accounts of scientific work are important to students' engagement with school science and attitudes towards science. In the face of its results, this study highlights the relevance of these statements, especially when most of the observed lessons were very constrained by curricular and assessment pressures, and by the scarcity of resources available for teachers to try to overcome this lack of diverse and contextualised historical accounts.

Here, I agree with Buck and colleagues (2008), Christidou (2011), Erduran (2014) and Ideland (2018) on the importance of diversifying science curricula if we aim to change the view that 'scientists are not like us' (not only in the case of girls, but also in the case of different cultural backgrounds). But how might this come about?

My main aim with this project was to explore the part HOS can play in this process of counteracting traditional (and mostly Eurocentric) views about scientific development, but only if disassociated from an illustrative/decontextualised approach and associated with a more intercultural/global perspective. During my Implementation phase I opted to examine the possibilities offered by an intercultural model of HOS for the realities of school science, focusing on how different scientific concepts have been developed through exchanges and collaborations between different people and cultural traditions. Regarding the possible impact of this approach, students from this Exploratory phase seemed interested in learning more about scientific research and technological developments done by different people in different parts of the world after some historical examples[71] were briefly introduced to them as prompts during our interviews:

> Student P[72]: "I like learning about the ones maybe from my culture because **it's inspiring for me to know that people that are from the same country as me can also do empowering things**. That's aspirational."
> Student Q[73]: "I think also like, how we leave them out in our science lessons. **Because we don't talk about the background of this, all we know is just European ones.**"
> Student R[74]: "I think it's interesting, because **I think we always have this stereotype that everyone was dumb before they were colonised by the Europeans**. It actually opens your eyes. It opens a lot of questions."

Their reactions to the examples have a lot to say about how scientists are portrayed by school science, even if after only a brief moment of discussion. And, more importantly, they are an indicative of the potential of an intercultural and contextualised approach to HOS, which will be further explored in my analysis of the Implementation phase.

[71] Metal technology in Africa; Arabic astronomy; Indian maths; Chinese inventions; Medicine in the native Americas.

[72] Year 8 – set 2 – School B

[73] Year 10 – set 1 – School A

[74] Year 10 – set 1 – School B

5.3. Thinking about science: students' understandings about NOS

Throughout chapter 2 and the previous sections in this chapter I argued that the use of HOS and intercultural perspectives in school science can offer insights to teaching about how scientists and the scientific community work, that is, about NOS. As part of this Exploratory phase, one of my aims was then to investigate what participant students knew about this topic, and the relationship between their ideas and the realities of school science discussed in relation to my RQ1.

The goal of this section is to present and analyse data generated by the NOS questionnaire, observations and interviews carried out with participant students and teachers, addressing RQ3: "What are participant students' main understandings about NOS? What can be influencing and shaping these understandings?". The analysis of the second part of this question ("what can be influencing and shaping these understandings?") will be mainly informed by a multi-layered take on the data generated through the different methods employed here. That is, more than simply describing students' views about NOS, I am keen to understand how school science (including teachers' practices, curriculum and assessment dimensions, among other features of this complex reality) can be impacting these views, inspired by the CR approach discussed in chapter 3.

The main findings from this stage will be presented in subsection 5.3.1 ('Students' understandings about NOS') and further explored in subsections 5.3.2 ('General analysis of students' understandings about NOS') and 5.3.3 ('Further reflections: NOS and school science'). In subsection 5.3.4 I will then discuss possible implications of these findings for my Implementation phase.

5.3.1. Students' understandings about NOS

As explained in chapter 4, students' answers to the NOS questionnaire were coded qualitatively in the form of statements developed through an inductive approach towards the data. All the 37 statements built as codes for theses answers can be found in appendix 10. These inductive statements were organised and connected through the method of data visualisation known as 'Epistemic Network Analysis' (ENA), which consists of a displaying interconnections (networks) between ideas (statements) within a group. Following the procedure described in chapter 4, ten networks were generated: one for each participant class (nine in total – seen figures 10 to 18 below), and one comprising answers from all 200 participant students from both schools (figure 1 in chapter 4).

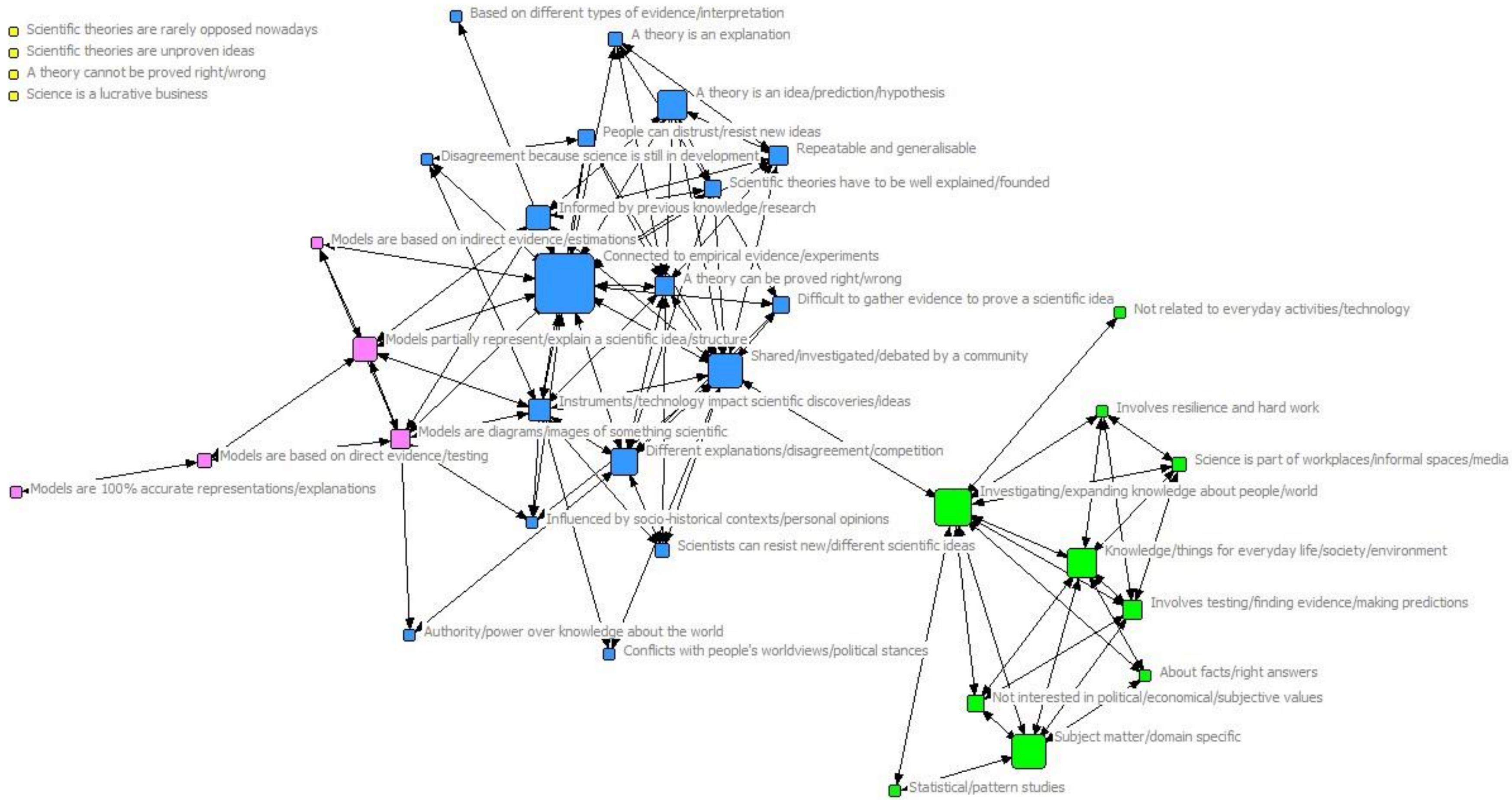


Figure 10. ENA of students' answers to the NOS questionnaire – school A year 8 (n = 24)[75]

[75] The colour scheme refers to clusters of statements: pink: models & theories; green: purposes of science; blue: production of scientific knowledge; yellow: disconnected statements.

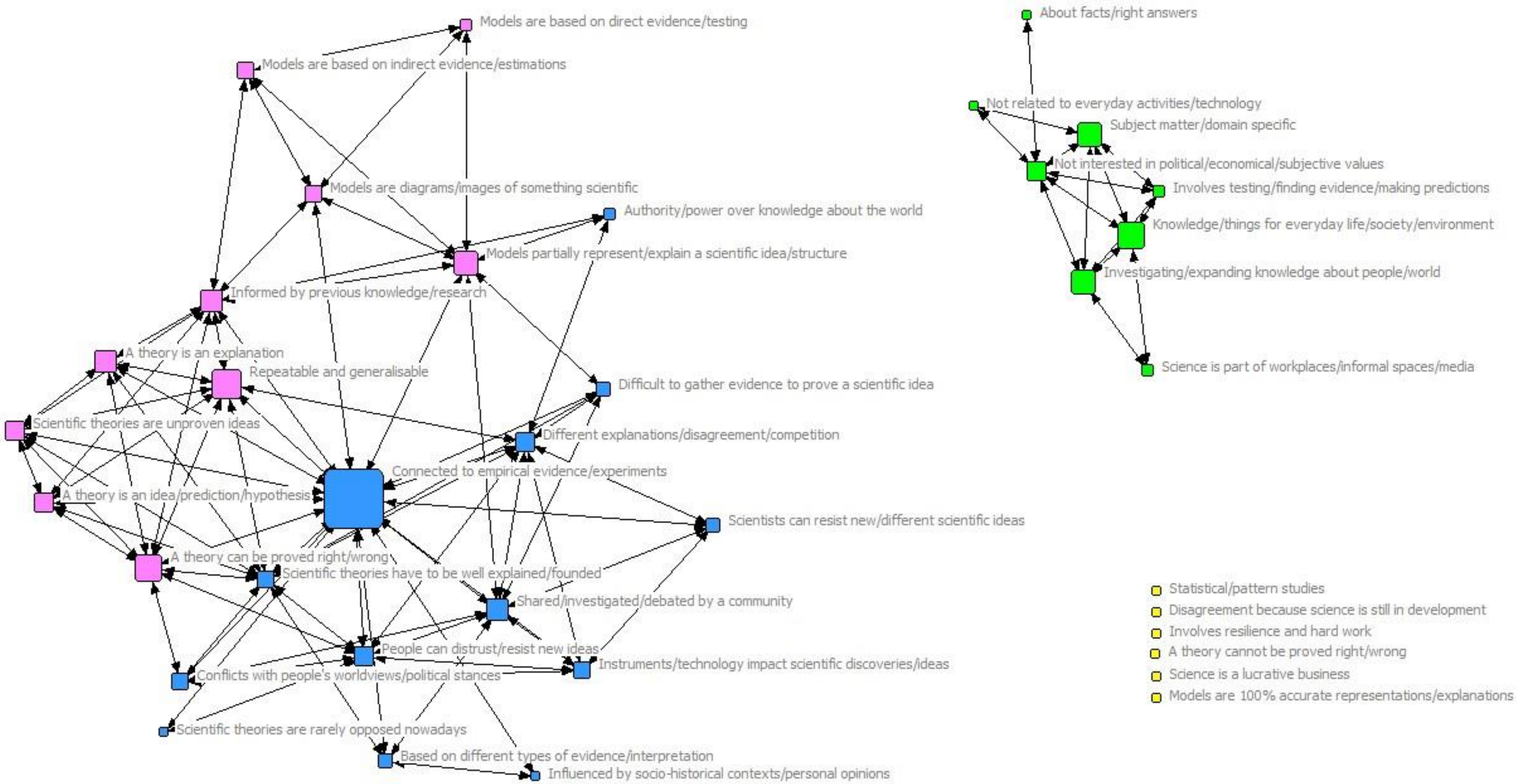


Figure 11. ENA of students' answers to the NOS questionnaire – school A year9 set1 (n = 25)[76]

[76] The colour scheme refers to clusters of statements: pink: models & theories; green: purposes of science; blue: production of scientific knowledge; yellow: disconnected statements.

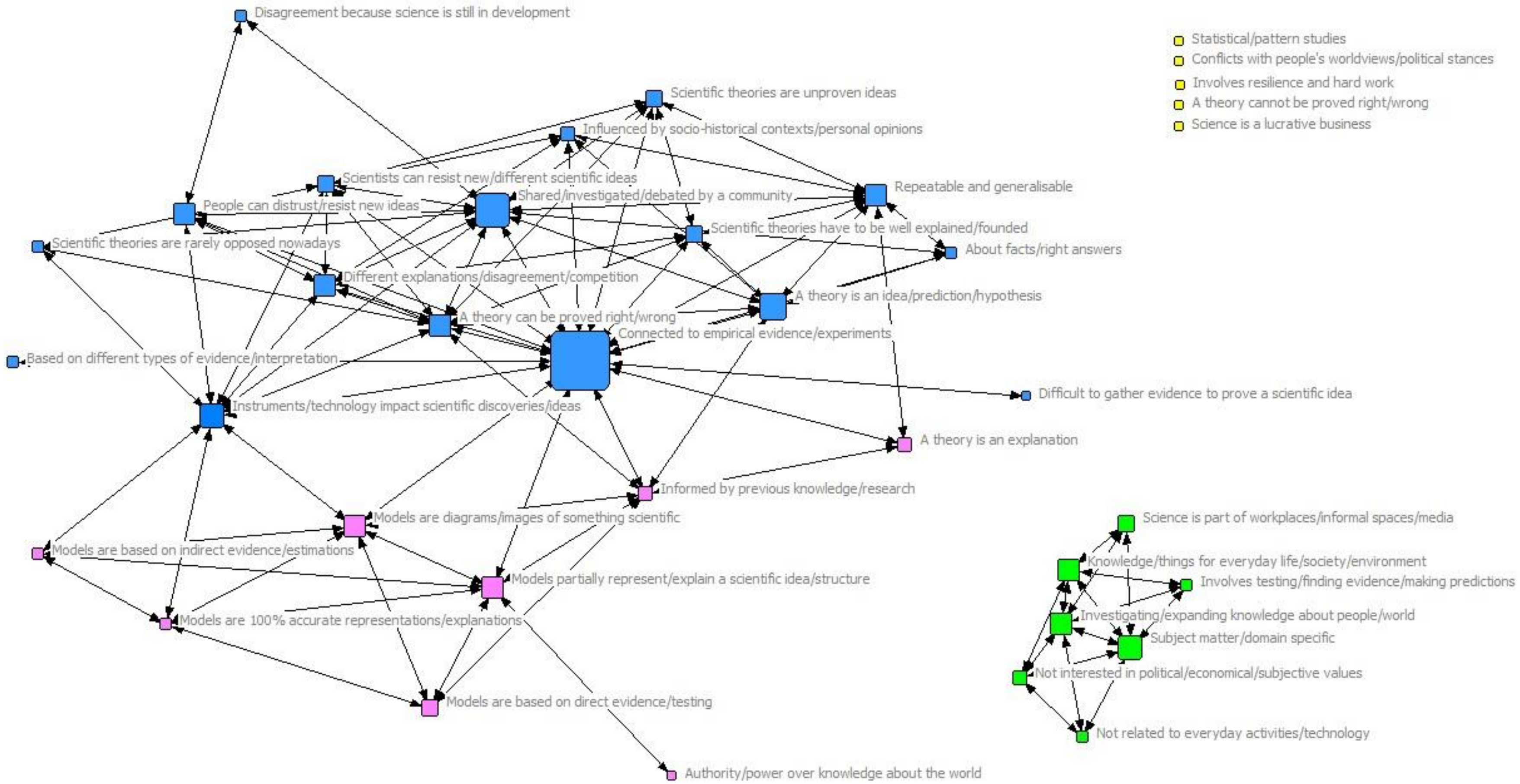


Figure 12. ENA of students' answers to the NOS questionnaire – school A year9 set2 (n = 23)[77]

[77] The colour scheme refers to clusters of statements: pink: models & theories; green: purposes of science; blue: production of scientific knowledge; yellow: disconnected statements.

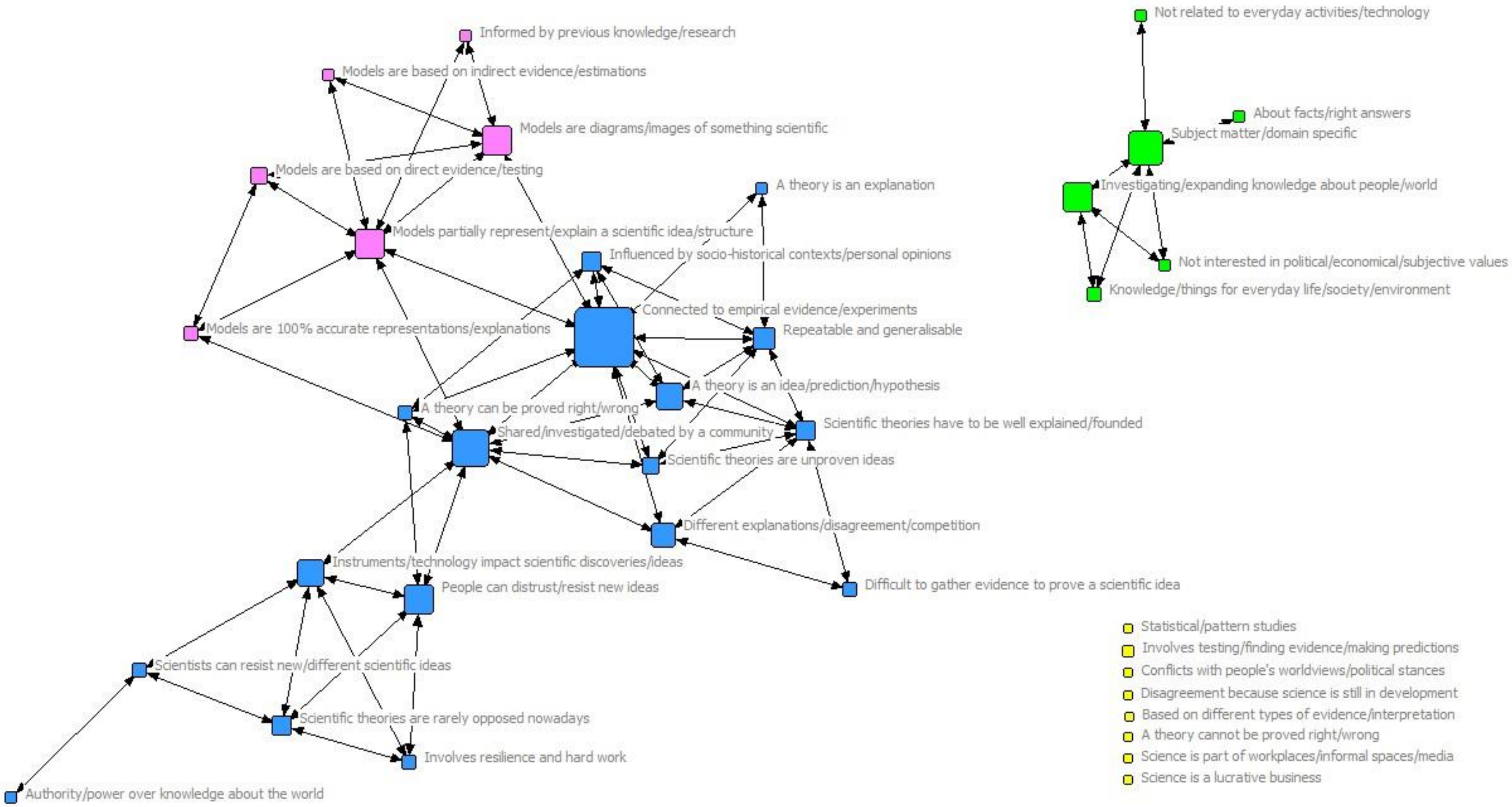


Figure 13. ENA of students' answers to the NOS questionnaire – school A year9 set3 (n = 15)[78]

[78] The colour scheme refers to clusters of statements: pink: models & theories; green: purposes of science; blue: production of scientific knowledge; yellow: disconnected statements.

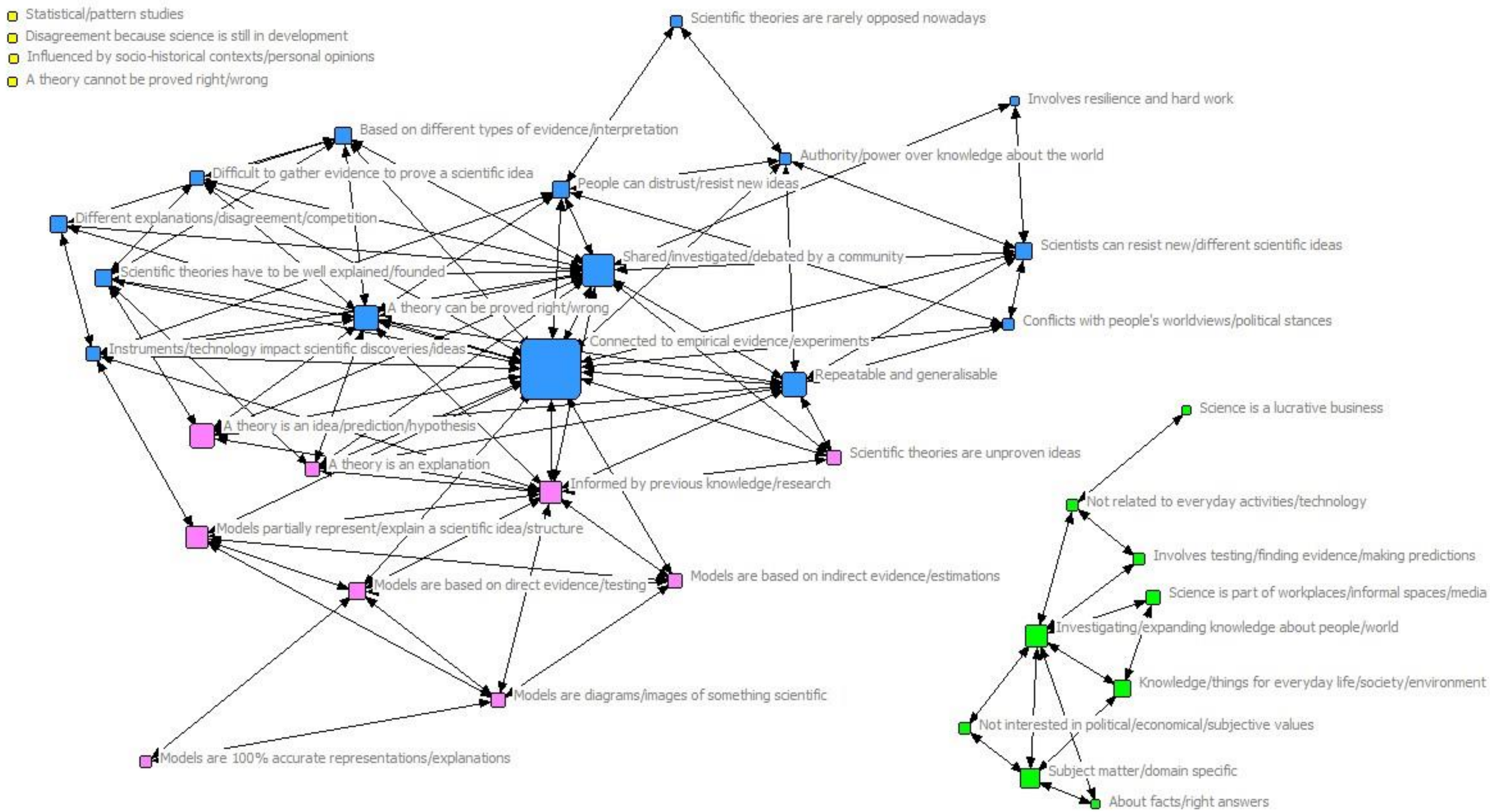


Figure 14. ENA of students' answers to the NOS questionnaire – school A year10 set1 (n = 25)[79]

[79] The colour scheme refers to clusters of statements: pink: models & theories; green: purposes of science; blue: production of scientific knowledge; yellow: disconnected statements.

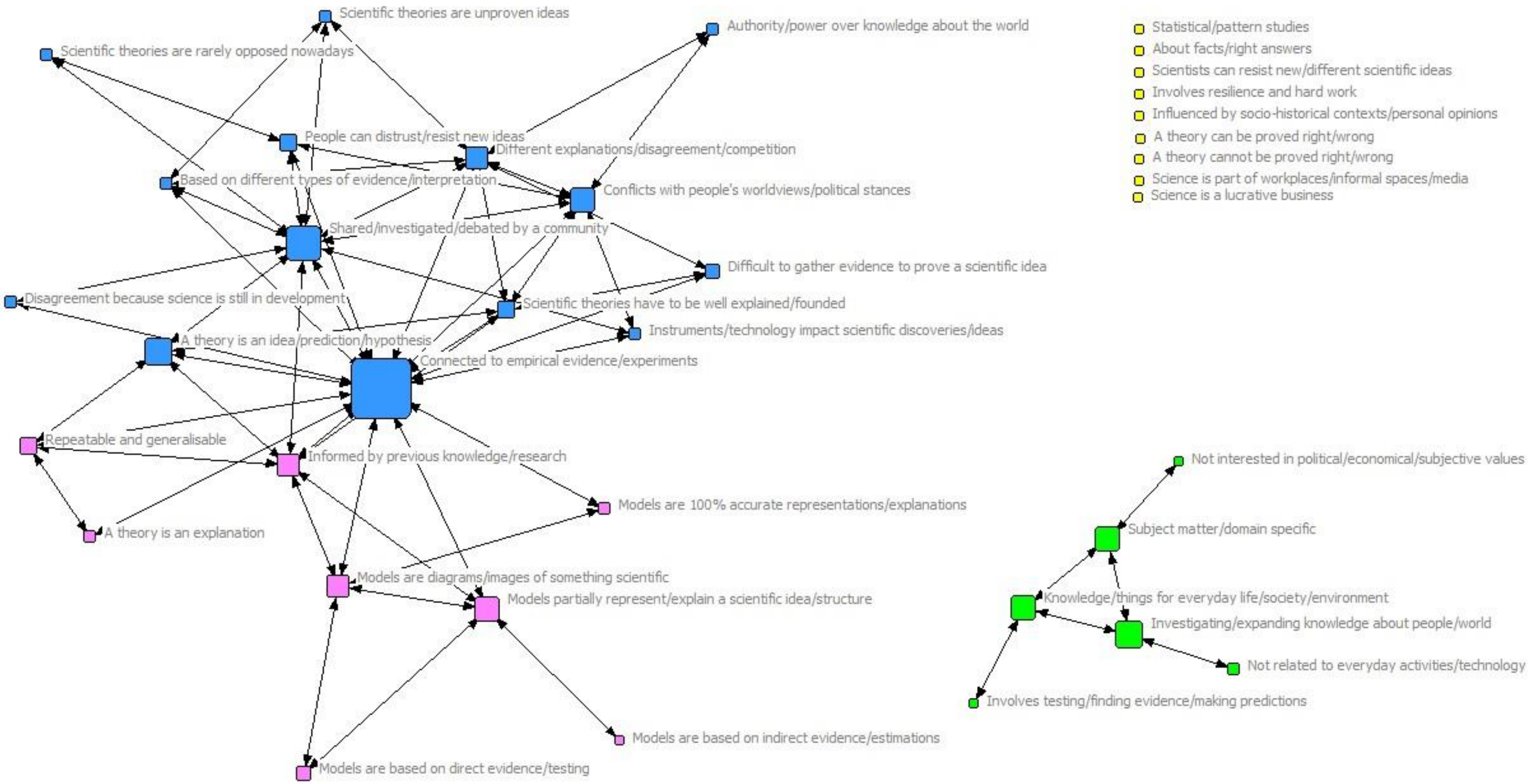


Figure 15. ENA of students' answers to the NOS questionnaire – school A year10 set2 (n = 21)[80]

[80] The colour scheme refers to clusters of statements: pink: models & theories; green: purposes of science; blue: production of scientific knowledge; yellow: disconnected statements.

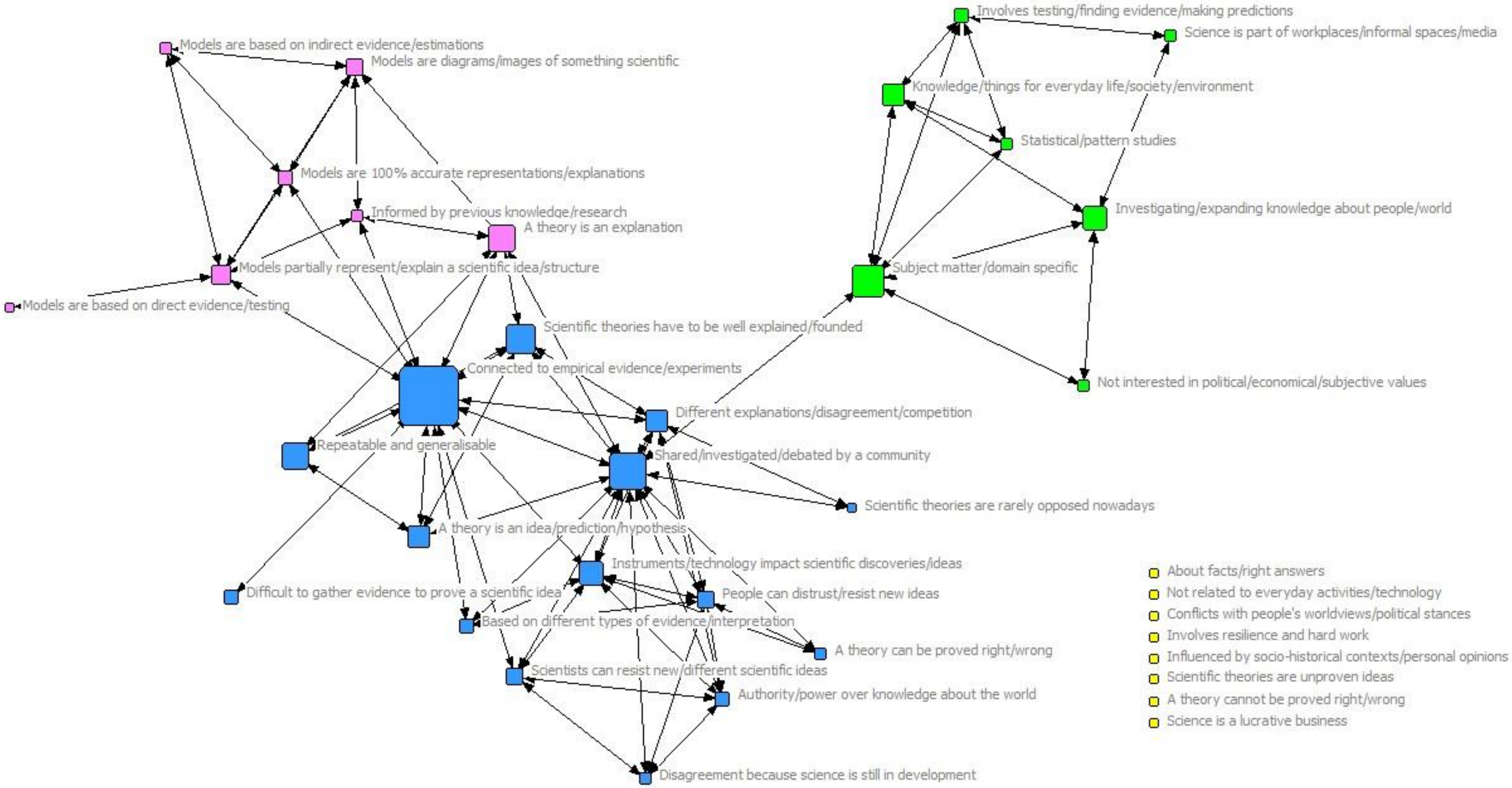


Figure 16. ENA of students' answers to the NOS questionnaire – school B year8 set2 (n = 27)[81]

[81] The colour scheme refers to clusters of statements: pink: models & theories; green: purposes of science; blue: production of scientific knowledge; yellow: disconnected statements.

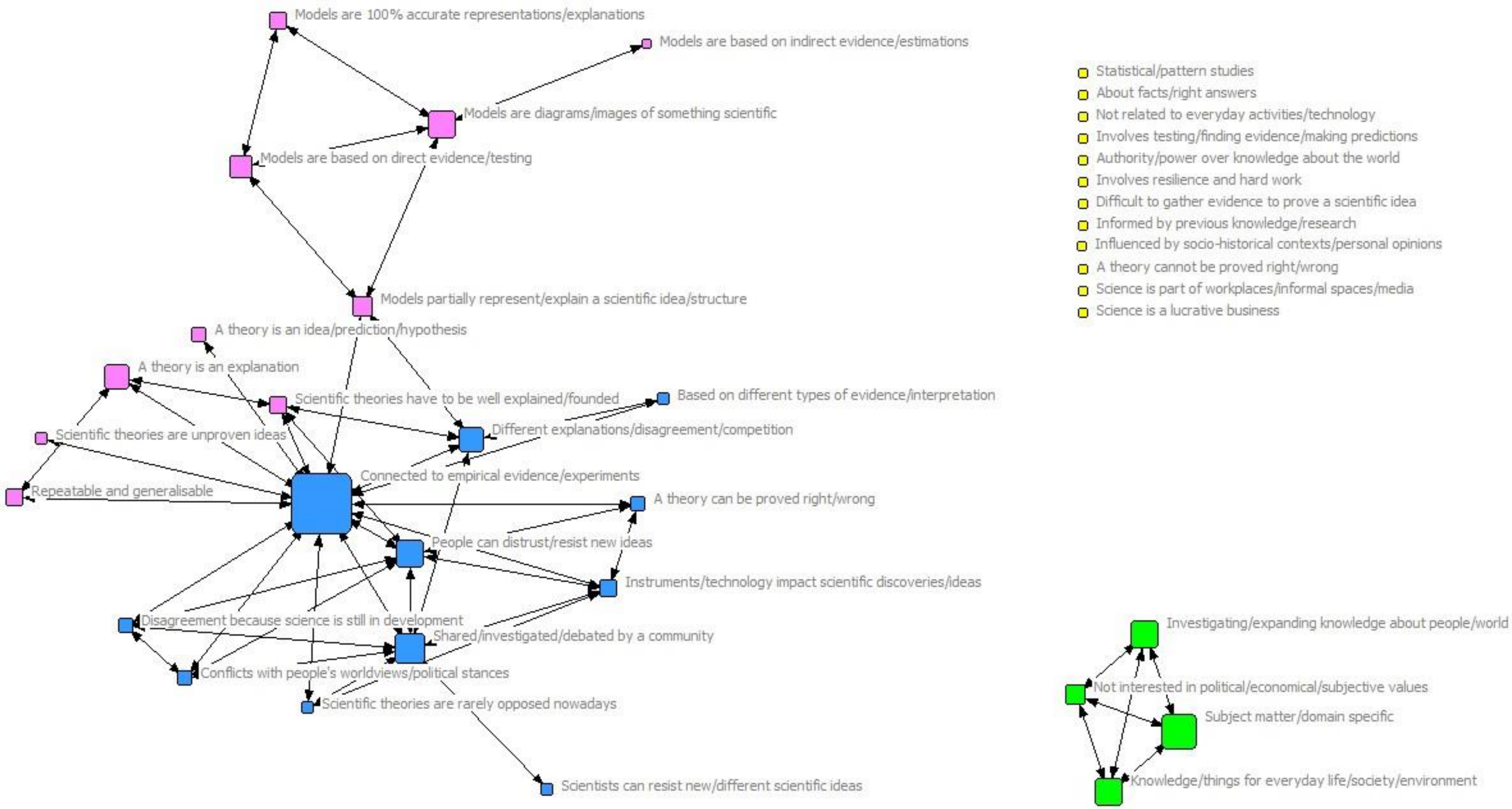


Figure 17. ENA of students' answers to the NOS questionnaire – school B year9 set3 (n = 17)[82]

[82] The colour scheme refers to clusters of statements: pink: models & theories; green: purposes of science; blue: production of scientific knowledge; yellow: disconnected statements.

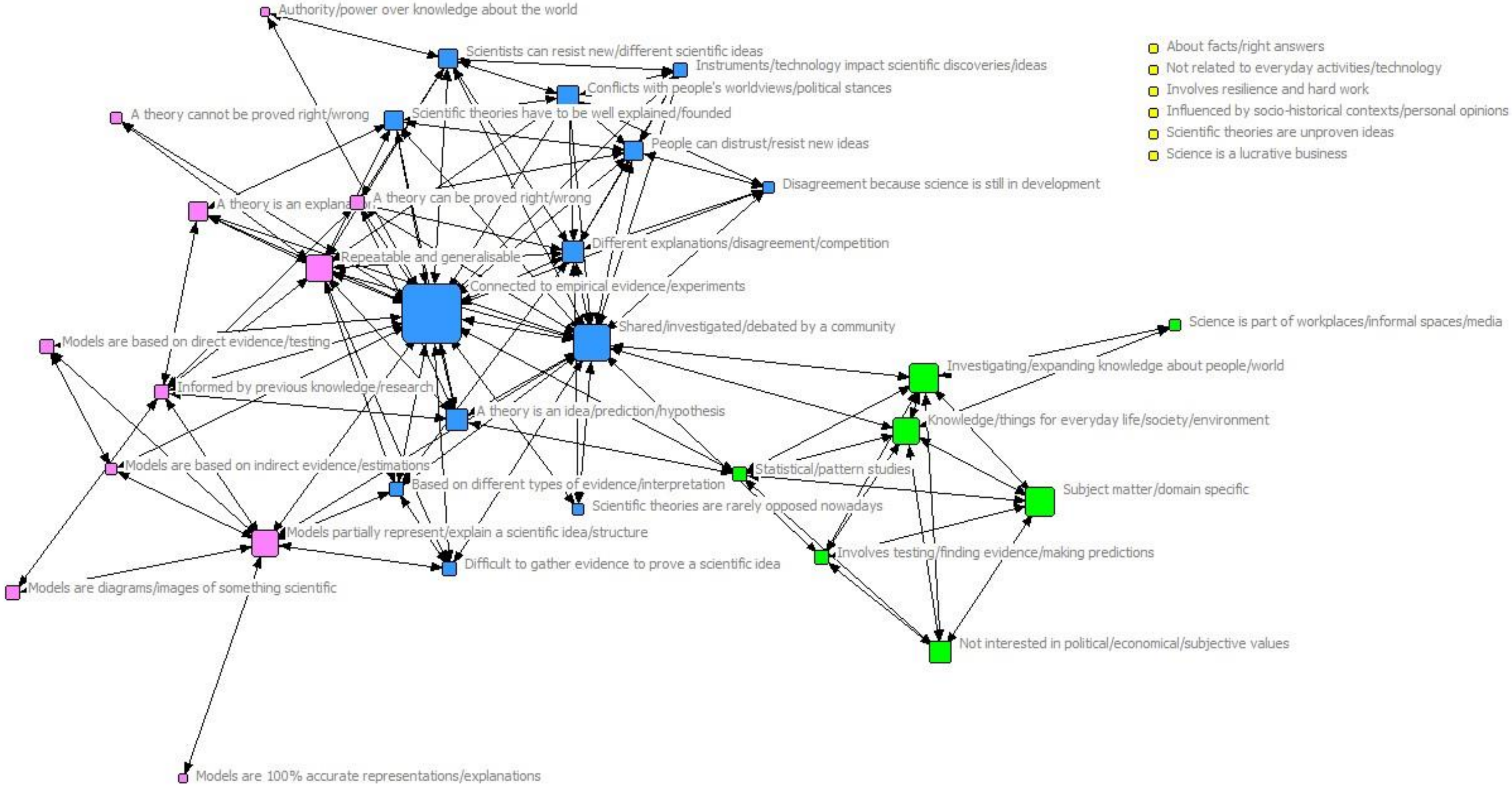


Figure 18. ENA of students' answers to the NOS questionnaire – school B year10 set1 (n = 27)[83]

[83] The colour scheme refers to clusters of statements: pink: models & theories; green: purposes of science; blue: production of scientific knowledge; yellow: disconnected statements.

These networks displayed similar clusters of statements. In an epistemic network clusters are groups of ideas frequently employed by the respondents together, appearing on the maps closer to each other than to other ideas. In this study, three main clusters were identified in all networks – models & theories (pink); purposes of science (green); and production of scientific knowledge (blue) – and their presence can be linked to the instrument adopted: since the NOS questionnaire also contained three types of questions (purposes of science – Q1 and Q5; models and theories – Q4 and Q6; scientific work – Q2, Q3 and Q4), statements arising from specific questions were expected to be near to each other on the maps.

Another relevant pattern found in relation to these clusters was their position on the map. While the 'production of scientific knowledge' group is central to the network (holding relationships with both other groups in almost all the cases), 'models & theories' and 'purposes of scientific knowledge' groups are usually far away from each other, alluding to a general disconnection between these two groups of ideas in students' views of science. Also, these two clusters are usually widely spaced on the maps, which means they do not generally establish close relationships with other statements and among their own statements.

Two explanations can be given to this phenomenon. First, students can have fewer things to say about 'models & theories' and 'purposes of scientific knowledge' than about 'production of scientific knowledge'. Second, the questionnaire might have given students more opportunities to talk about 'production of scientific knowledge' than about 'models & theories' and 'purposes of science' in terms of the types of questions asked. Questions about 'production of scientific knowledge' might have promoted more diverse answers, while questions about the other two topics might have been more closed and less overarching, constraining the possibilities for connections between different statements.

Even though the NOS questionnaire certainly impacted the clustering on the networks, relevant connections were established among the statements and some general views about NOS can be identified. As previously mentioned, the work with ENA enables the study of:

- The most frequent statements employed by the students to talk about NOS (size of the node);
- Statements that are central to students' views about NOS – the most connected ones (centrality of nodes);
- Statements that are closely connected to each other and the ones that are the least connected to the main ideas of the network (proximity of ideas/distance between nodes);

- The total number of statements employed by a group of students to talk about NOS;
- The diverse nature of the connections between statements made by the students (density of the network).

Table VIII (appendix 16) displays the main features of networks produced in this study, and some of these trends can be summarised as follows:

- First, the number of statements employed by students to talk about NOS ranged from 26 to 33, and the density of the networks produced varied between 13.1% and 20.8%, figures that are comparable with other similar research about NOS at a pre-intervention stage (Peters-Burton & Baynard, 2013; Peters-Burton, 2015). In general, these numbers imply that although a group of students can have diverse views about NOS (high number of statements in all groups), these views are not necessarily complex/broad at the individual level (number of connections made by each student within the group) for all the groups. In other words, views about NOS can be variable in the same class (high number of statements), but that does not mean these ideas result in connections being made by students (low density – connections). That was the case of groups with density figures around 13-15%, which are considerably lower than results from similar research (Peters-Burton, 2015) and from other participant groups in this research.

- Second, the most frequent individual ideas employed when talking about NOS did not vary among the classes (i.e. among different schools, year groups or ability groups), being mainly concentrated on the following statements: "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". Most of these statements are part of the cluster 'production of scientific knowledge', the most central group of ideas in all networks.

- In relation to centrality, it is fair to expect the most frequent statements about NOS to also be the most connected (central) ones. This can suggest the existence of some 'core ideas' that generally pervade participants' views on NOS. Additionally, some ideas about NOS that are moderately frequent in the networks are also often connected to other statements, such as: "A scientific theory can be proved right or wrong"; "Scientific theories have to be well explained/founded"; and "It's important for scientific theories to be repeatable and generalisable".

In the next subsection, these main findings will be further explored, focusing on these ‘core ideas’ that permeate most students’ views about NOS, how they are connected to other ‘peripheral ideas’, and which ideas are not being employed or are largely disconnected from their central views.

5.3.2. General analysis of students’ views of NOS

Views about the production of scientific knowledge

The cluster ‘production of scientific knowledge’ was usually at the centre of the networks, indicating its relevance to students’ ideas about NOS. This group of statements is mainly connected to how scientists work to produce scientific knowledge, both from epistemic and social-institutional perspectives.

An initial analysis shows that some core ideas about scientific work are highly connected within the group, pervading most answers. For instance, “a theory/model has to be strongly connected to empirical evidence/experiments to be accepted” (statement #12) was linked to ideas like disagreement between scientists (“There can be different explanations, disagreement and competition among scientists” – #11), misunderstandings (“Scientific theories can be based on different types of evidence and interpretation” – #21), proof for ideas/theories (“A scientific theory can be proved right or wrong” – statement #29), and durability of scientific knowledge (“It's important for scientific theories to be repeatable and generalisable” – #23).

Here, it is worth noting the relevance participants placed upon empirical evidence [the ‘empirical explanation’ approach, as seen in Driver and colleagues (1996)]. According to most answers given by these students (also during our interviews), the main issues in science can be solved by “gathering more evidence” and “doing more experiments”, and disagreements between scientists are due to the lack of evidence available to “prove their point”. As also found by Rudge and others (2014) with pre-service teachers, there is a predominance of ideas about scientific work as connected with the quality and quantity of the evidence provided.

During our interviews, when talking about evidence in science, most students emphasised that evidence is something visual and physical that you need to “back up your point”, to “justify your solution to a problem”, a “proof that what you are saying is real”. This result is similar to other research (Kang et al., 2005; Rudge et al., 2014; Fouad et al., 2015), including to that of Driver and colleagues’ (1996, p. 98), who found that students of different ages tend to hold an empiricist/objectivist view that all “reliable knowledge is necessarily based on direct perceptual evidence”. There was also a tendency, especially in our interviews, to describe evidence as “proof” or “facts”/“factual information", something that "scientists are 100% sure about" and "people will believe in".

Although some participants mentioned interpretation of evidence ("Scientific theories can be based on different types of evidence and interpretation" – #21), difficulty to access evidence ("It can be difficult to gather evidence to prove a scientific idea" – #20), the influence of technology and access to it ("Instruments and technology impact scientific discoveries/ideas" – #10), and of previous knowledge/research field ("Scientific theories and models can be informed by previous knowledge/research on the topic" – #22), these were still peripheral ideas in relation to the use of evidence in science. In other words, participant students seem to hold a view of scientific work as mainly based on gathering evidence, with less concern about the processes of doing it and how it can be impacted by different factors – the 'social explanation' approach towards scientific work (Driver et al., 1996).

Furthermore, they appear to hold a static view about the importance of evidence to scientific work: once enough evidence is found, a scientific idea is proven and will probably not change in the future. This is similar to results from other recent investigations (Rudge et al., 2014; Fouad et al., 2015) and also to Driver and others' study (1996, p. 128) published more than 20 years ago, which seems to still resonate here: "there is widespread confidence that empirical evidence can unproblematically resolve issues of theory choice and reveal 'how the world is'". During this investigation, very few students were the exception and talked about how new technology can provide different evidence to support an idea (as exemplified by student A[84]), or how evidence can be challenged (as mentioned by students B and C[85]):

> Researcher: "So, what happens if in 50 years you have a new piece of evidence that changes everything?"
> Student A: "I think that's why we develop old theories, because **the technology 100 years ago wasn't as advanced to provide that evidence**. So that's why we kind of **build up on old theories and stuff**."
>
> Student B: "If they have **evidence for their point and you have evidence for your point, we don't know who is correct, because both of you have evidence to go and support your point** [...]. They both have evidence [in the case of the question about the dinosaurs], one to go **and just prove their case** and one in favour of the other case. And the real question is, the **key piece of evidence was to go and find evidence that disproves one of them**, because that assures you who is really correct. You can always find evidence for something, **there is always something that might**

[84] Year 10 – set 1 – school A

[85] Year 10 – set 1 – school B

mean something else. And sometimes **evidence might not be 100% correct**, like you can go and find a piece of evidence and think about it in a certain way to support you hypothesis. However, **when someone else sees that evidence, they don't really see the connection between your hypothesis and that piece of evidence, they don't think that it will lead to that**."

Student C: "**Evidence can be interpreted in different ways** and scientists are the ones to kind of put those interpretations forward. It's a **collective discussion** between lots of different people. **I guess the one you agree on most is the one that we consider right**."

Another statement in this cluster was "scientific ideas are shared/investigated/debated by a community of people" (#19), encompassing answers related to scientists checking each other's works, communicating their findings, exchanging and debating new ideas/evidence. Here, students tended to associate this idea with other social-institutional statements, such as "scientific theories have to be well explained/founded" (#16), "scientists can resist new or different scientific ideas" (#9), and "there can be different explanations, disagreement and competition among scientists" (#11).

In most participant classes, however, these statements were, in general, peripheral to more evidence-based ones, and were usually connected to the final stages of scientific research, where scientists are supposed to analyse and criticise each other's works after those have been published. That is, even though students placed collective work as part of the production of scientific knowledge, it seems that the emphasis here is more on the importance of the community of scientists to check each other's claims than to collaborate during the scientific work itself. For instance, very few students talked about the importance of sharing evidence, instruments and ideas in the question about the extinction of dinosaurs (e.g. "share different evidence and ideas to come up with something big, with a better explanation"[86]; and student B in the quote above), similar to results obtained by Fouad and others (2015).

Therefore, Driver and others' (1996, p. 131) summary of their findings seem to still be relevant regarding students' adoption of purely 'empirical explanations' instead of also taking 'social explanations' for scientific work into account:

> What was less represented was a view of science in which theories are seen as conjectural and underdetermined by data, where measurements are seen as having inherent uncertainty, where scientific 'facts' are seen as products of social as well as empirical processes, rather than a reading of nature.

[86] Year 8 – set 2 – school B

Views about models & theories

Although ideas about models and especially theories were sometimes found in the ‘production of scientific knowledge’ cluster, this specific group named ‘models & theories’ encompasses answers about these topics that somehow were not very connected to the central cluster. Therefore, while still linked to this cluster, statements about models and theories tended to be more peripheral than other ideas.

We can see the predominance of two different views about scientific models on the networks: they are representations of ideas and help to explain those ideas (“Models can help to partially represent/explain a scientific idea or physical structure” – #24), or they are diagrams or images of something (“Models are diagrams or images of something scientific” – #36). In this scenario, it is important to remark that all participants had already been in contact with scientific models at the time of this investigation but results here show a heterogeneous view about what they are and, more importantly, why and how they are produced.

Similar to my discussion about the central cluster, it seems that students tend to understand science more as a product than as a process of knowledge production. As also found by Driver and colleagues (1996) and Kang and colleagues (2005), the focus here seems to be on static/representational ideas about models (#36) in detriment of more dynamic, non-definitive and explanatory aspects (#24).

In relation to theories, students’ answers focused mainly on them as explanations (“A scientific theory is an explanation for events/phenomena” – #28) and as predictions/hypothesis (“A scientific theory is an idea, a prediction or a hypothesis about something scientific” – #27). There were also answers related to theories as unproven ideas (“Scientific theories are unproven ideas” – #26) or as having yet to be proved as right/wrong (“A scientific theory can be proved right or wrong” – #29). These results are akin to those in Solomon and others (1996), Kang and others (2005), Rudge and others (2014), and in Driver and others’ (1996) study, which used a probe similar to my Q4, obtaining these categories: “theory is a vague idea”; “theory is a prediction”; “theory is an explanation”.

Students then hold mixed views about what scientific theories are and, more importantly, about their status as a type of scientific knowledge in opposition to the general meaning of the word ‘theory’ in many languages. Therefore, explicit discussions about the nature of scientific theories seem to be missing from these students’ experiences of school science. As argued by Nola (2016), Allchin (2017) and McComas (2017), this can be a relevant issue in the current scenario where scientific theories (e.g. the theory of Evolution or the Big Bang theory) are being dismissed by anti-science groups as simply an ‘idea’ or ‘opinion’, without any further discussions on the actual meaning of this term in the scientific context or how those theories are generated as part of a complex process of knowledge production.

Lastly, the connection between these ideas about models and theories and the cluster 'production of scientific knowledge' was mainly through the central statement regarding empirical evidence ("A theory/model has to be strongly connected to empirical evidence/experiments to be accepted" – #12). Furthermore, there was a slightly larger emphasis on direct evidence ("Models are based on direct evidence/testing" – #34) than on indirect evidence ("Models are based on indirect evidence and/or estimations" – #33) as the main source of information to the production of models. Another idea here, although peripheral, was that "scientific theories and models can be informed by previous knowledge/research on the topic" (#22), following the pattern seen in the central cluster of downplaying social relations as factors affecting scientific work, with more emphasis on empirical/direct evidence.

Views about the purposes of science

The cluster named as 'purposes of science' was generally the most disconnected in the networks. Some relevant trends, however, can be found within this cluster about students' views on what science is about. The most central idea here (and, in fact, one of the most frequent statements on the networks as a whole) was that "science is a subject matter/domain specific" (#4). This means that most students tend to associate science and its purposes, activities and questions with the specific fields of Biology, Chemistry and Physics [the 'domain of the question' category, according to Driver and others (1996)]: questions and tasks are considered scientific when they are clearly connected to one of these domains (e.g. "this is a scientific question because is related to Biology" or "taking care of animals in your everyday life is related to science because it is related to Biology").

This trend was especially common in Q1, where students were asked to evaluate different questions as scientific or not and is also similar to findings by Driver and others (1996) and by Fouad and others (2015). All questions were connected to the production of knowledge about something, but instead of focusing on how this knowledge was being produced (the process) to decide if the questions were scientific or not, students generally employed the domain of these questions (Biology/Chemistry/Physics/Humanities) to make this decision.

Even those students who did not use the field of the question to justify their choices employed more generic and utilitarian ideas about scientific work, as also found by other studies (e.g. Solomon et al., 1996; Kang et al., 2005), such as "science involves investigating and expanding knowledge about people and the world" (#1) or "science develops useful knowledge/things for everyday life, society and environment" (#3), and not about how those questions were going to be (or could be) investigated. This pragmatic and instrumentalist view of science can be related, among other factors, to a strong association between science and technology promoted by examples in school science, as seen in most lessons observed in this phase. As argued by Kang and others (2005, p. 323), "when students are thinking about science, they are likely to have a technologically oriented image of science such as inventing artifacts, medical and environmental research, and genetic engineering, etc."

In this scenario of a product-oriented view of science, ideas closely related to its processes were rarely employed by students, being some of the least frequent on most networks. Among these few ideas, usually connected to an 'empirical investigability' approach (Driver et al., 1996), there were: "science can involve statistical/pattern studies" (#5) and "science involves testing, finding evidence and/or making predictions" (#8), as also illustrated by student D[87] during our interview:

> Researcher: "Is this a scientific question [mentioning one item from Q1 in the survey about preferences about TV shows]?"
> Student D: "It could be... **Collecting data and collecting evidence to go and support a certain hypothesis**, like that kind of stuff. Because **you are not just answering any question that people have generally**, you need the science to that kind of science. So that will be I think Sociology. It would be a different part of science, it would still be considered science."

In summary, there seems to be an influence of school science on what students actually think science is about and how scientific work is portrayed. The use of the fields of Biology, Chemistry and Physics as indicators of scientific activities and the focus on appliances when using examples about these activities can hint to the type of science these students are in contact with. That is, science seems to be more related to specific groups of content (science-related subjects) and to the production of appliances than to processes of knowledge production. And even when they think of science as an activity involved in generating knowledge, little consideration appears to be given to how this knowledge is produced, both in relation to different methodologies employed and to its limits/boundaries and to the questions it can and cannot answer.

In the next subsection, I will explore the impact that school science can have on these views about NOS. Some differences and similarities found among the participant classes will also be highlighted and discussed in connection with my interviews with participants, and with some lesson observations carried out during this research phase.

[87] Year 10 – set 1 – school B

5.3.3. Further reflections: NOS and school science

In the previous subsections, general trends related to secondary school students' views about NOS were presented, bringing into light: an overreliance on the importance of empirical evidence to scientific work; a focus on verification of each other's final works when talking about the scientific community; a general idea that models and theories are static and only empirically-based; and that scientific work is bounded to the domain of the investigation and to the production of appliances. If we look at these findings from a multi-layered perspective, some can be easily linked to school practices observed during this investigation and to conversations had during my follow-up interviews with participant teachers and students.

For instance, when epistemic aspects of NOS, such as theories, models, predictions and use of evidence were part of the lessons, the majority of the participant teachers adopted (deliberately or unknowingly) an implicit approach towards these aspects (i.e. no active discussion about these ideas), as exemplified by teacher B's use of atomic model kits on the fuel choice example and by teacher P's task 'Actions and Consequences' discussed in section 5.1. These 'missed opportunities' to explore epistemic aspects in the lessons can account for students' uncritical overreliance on evidence as the solution for any question in science, for their heterogeneous views on what theories and models are, and for their lack of understanding about the collective and dynamic aspects of the production of scientific knowledge (e.g. gathering and interpreting evidence and generating models and theories).

Similarly, the focus on examples of everyday objects and appliances also mentioned in section 5.1, while useful to bring the topics of the lessons closer to students' realities, can be linked to their emphasis on applied aspects when thinking about the purposes of scientific work. In addition, an illustrative approach to these examples, only paying attention to their usefulness and not to the processes involved in their production, might also be connected with this view of science mainly as a 'product' and not a 'process'.

This focus on science as 'a source of appliances' to society can also account for the scarcity of answers connecting the production of scientific knowledge with social-institutional aspects. Here, teachers' already cited avoidance in discussing more 'internal' aspects of the scientific community (such as how different theories can be compared, and how this community chooses between them) and their option of focusing on social aspects mainly related to the 'usefulness of science' might be one explanation for students' less dynamic and more individualistic views about the production of scientific knowledge.

Students' views about NOS also varied among the specific classes investigated in this study, as seen in their networks (figures 10-18), especially from one curriculum cycle to another (KS3 versus KS4) and among different ability groups. For instance, a brief comparison between the network produced by school A year 8 (KS3), 9 and 10 (KS4) groups can wield some information regarding curricular differences. First, this year 8 is the only group in the school that linked the cluster 'purposes of science' to the central cluster 'production of scientific knowledge', alluding to an interconnected view of scientific work and the purposes of science. Similarly, the cluster 'models & theories' should in fact have been named only 'models' in their network, mainly because their ideas about theories are much more integrated into the 'production of scientific knowledge' cluster than as seen with other groups.

This is not to say, however, that this year 8 group held more complex views than groups following the KS4 curriculum at school A. In fact, regarding the number of statements and the density of the networks produced at this school, the KS3 group had similar results to those from KS4 groups[88]. Nevertheless, even if this year 8 group does not hold a more complex view of NOS, we can at least infer that science lessons in KS4 do not appear to be deepening students' knowledge about scientific work after they finish their KS3 studies.

This scenario can be linked to my previous discussions about how science lessons and the science curriculum for KS4 groups have been dealing with NOS. During my observations and interviews throughout this phase, it became clear that teachers had more freedom of content and time to have explicit discussions about NOS with their KS3 groups than with their KS4 groups. As previously argued, curriculum and assessment demands involved in teaching the KS4 curriculum can then have great impact on which and how aspects of scientific knowledge will be addressed (Höttecke & Silva, 2011; Hodson, 2014a, Henke & Höttecke, 2015).

Teachers also recognised this impact of assessment on how students talk about science. For instance, teachers F and B believe that students in KS3 seem to feel less pressure to get things right than the ones in KS4, tending to engage with the lessons more openly and to discuss different topics such as NOS. On the other hand, these teachers also remarked that students in KS4 groups are usually very aware of the overwhelming presence of specific demands in their high-stake exams. During our interviews, some participants (e.g. year 9 set 1 school A) talked about this focus on teaching and learning content for their exams:

> Researcher: "Where did all these ideas [about NOS] come from? Where did you learn about them? Do you talk about that in the science lessons?"

[88] Except for year 9 – set3 and year 10 – set2, whose networks were considerably less dense.

Student E: “They’re **from thinking by myself**.”

Other students: “Yes.”

Student F: “To be honest, **I don’t think they actually teach us** about that in the educational system, they just want us to **focus on what we need to pass our exams** and get the jobs that will be helpful for the future.”

Another difference between the networks produced in this investigation was related to ability groups (mixed, sets 1, 2 and 3). For instance, at school B, years 8 and 9, although involved in the same (KS3) curriculum, yielded very different results. It was expected that the year 9 group, formed by older students with more experience of school science, would generate a more complex and diverse network about NOS than the year 8 group. It is clear, however, both numerically (statements and density of the network) and visually, that the latter is more complex and diverse than the former.

One of the possible reasons for this difference (also seen in the case of the year 9 set 3 at school A) is that these students were part of different ability groups. During my observations of their lessons, the division of students in ability groups often impacted teachers’ lesson planning, as already argued in section 5.1, with more emphasis placed on the content with students from the lower ability groups and on more critical and in-depth discussions about science with high ability students. In this scenario, teachers from school A mentioned how these latter groups have higher expectations placed upon them, so teachers often try to stimulate different discussions in their lessons when compared to lower ability groups, where problems with behaviour and underachievement constrain, in their opinion, their freedom to expand the curriculum.

It is worth observing, however, that even if placed under this umbrella of behavioural and underachievement problems, students from lower sets (such as year 9 set 3 at school A) seemed to be interested in talking about NOS during our interviews:

Researcher: “Do you like to talk about these ideas about how science works?”

Students: “Yes!”

Researcher: “Why?”

Student G: “Because **it’s interesting to think about this stuff**, things you never thought about before, about **how scientists got that knowledge**, and **we don’t do that** in the lessons very much.”

This interest in having more opportunities to talk about NOS was not exclusive to students in lower sets groups. During our interviews, there was a general positive engagement with our talks about the scientific world, and students seemed open to discussing their views with me. Nevertheless, KS4 students were also very aware of the impact and pressures of the curriculum on what they have time and what they do not have time to talk about during their lessons, as explained by student F in one of the extracts above ("they just want us to focus on what we need to pass our exams").

5.3.4. Final thoughts and implications for the Implementation phase

In this section I was interested in investigating the most common views students held when thinking about NOS, including the purposes of scientific work, production of scientific knowledge, and scientific models and theories, as summarised by RQ3: "What are participant students' main understandings about NOS? What can be influencing and shaping these understandings?". In addition, inspired by a multi-layered approach to the analysis of these results, my aim was to also understand the possible connections between these views and school science, especially in relation to science teaching practices, curriculum and assessment.

Students emphasised the importance of empirical evidence to scientific work, paying less attention to how this evidence is collected, interpreted and negotiated within the scientific community. Furthermore, when talking specifically about this community, they usually focused on "scientists checking each other's final works", with fewer mentions to, for instance, collaborations during the process of knowledge construction. Coupled with their often static and solely empirical views on theories and models and with their association of scientific work mainly with specific subjects and appliances, these findings highlight a general view of science as a finished product, as a group of knowledge that can be easily produced through the accumulation of enough evidence and ending with public checking of one's work.

School science then appears to be promoting a more instrumentalist and empiricist view of scientific work, while dedicating less attention to other important aspects involved in this endeavour. Among these aspects, which have been increasingly gaining recognition from the field of HPSS in the past half-century (Erduran & Dagher, 2014), there are the social-institutional elements and how they relate to epistemic features of knowledge production, as argued in chapter 2.

One could say, however, that school science is not actually promoting any specific views of NOS (instrumentalist or not), since allusions to these aspects were generally absent from most science lessons observed in this study. Nevertheless, can we really talk about a 'neutral impact' of school science on views about scientific work only because teachers are not explicitly exploring these ideas? As argued throughout chapter 2, different research (e.g. Driver et al., 1996; Deng et al., 2011; Allchin, 2012a; Hodson, 2014a) have shown that even if these discussions are not often part of school science, an implicit view of science is being communicated by teachers when they opt not to address these ideas.

Similar findings were obtained by this study, where the choice of teaching science mainly as a product, with little reflection about processes of knowledge production, resulted in more instrumentalist and empiricist views about it. When asked if they had the chance to talk about NOS during their regular lessons, all participant students interviewed here mentioned that this scenario was very rare, with teachers focusing on content in the examinations.

Not having these explicit discussions in their science lessons does not mean they are not forming their own ideas about how the scientific world works: students highlighted how they form these ideas "by themselves", while also using internet videos, webpages, TV shows and films, and discussions from the humanities lessons. Student F is an example of that ("from thinking by myself"), and others from school A (year 10 – set 1) offered offer further insight into it:

> Student A: "I think you develop them [ideas about NOS] **by yourself, we don't really discuss this in science lessons**. I think most ideas just come from yourself and what you think."
> Researcher: "And what about you?"
> Student B: "Yeah, the ideas **start from the learning of a concept at school and then I kind of develop them on my own** and try to see if they make sense."
> Student C: "I agree with both of them, and also I think **it has to do with media, films and TV shows**. Although some of them may not be true, but it does **help to give you an understanding of what actually is going on in the scientific world.**"

In this research, I am arguing that the importance of explicitly teaching about NOS in science lessons must not be ignored if we want to avoid the formation of distorted images about scientific work and scientists, such as disconnected from general society and individualistic. Nevertheless, as discussed throughout this chapter, the curricular and assessment constraints teachers face in their everyday practice can limit the amount of time they have to develop these more in-depth and explicit discussions about NOS, highlighting the need for teaching ideas that bring NOS and scientific content together within these limitations.

These findings were then of great relevance to the continuity of this investigation, that is, to my Implementation phase. Since it was my goal to work on innovative ways of introducing NOS into science lessons – mainly through a intercultural approach to HOS –, understanding these realities of school science in comprehensive secondary schools in England allowed me to identify practices and structures that hinder (e.g. implicit, illustrative and stand-alone approaches, focus on content and experimentation in official examinations) and those that foster (e.g. explicit in-depth discussions, interaction with students' own knowledge and ideas about a topic, explicit connection with regular content, assessment and curricular flexibility) NOS teaching and learning.

Findings from this Exploratory phase thus informed the Implementation phase in different manners. For instance: inspired by examples of work with NOS aspects seen especially in teacher F's and teacher K's lessons, the TLPs involved explicit group and whole-class discussions about NOS, aiming at stimulating students' explicit engagement with, and reflection about, these ideas. In addition, conversations about scientific development and communities were integral to the teaching different scientific content, that is, they were intrinsically linked to – and not separated from – understanding how these ideas ('products of science') had been developed ('processes of science').

In the scenario of exploring NOS elements in the TLPs, social-cultural-historical aspects of scientific work were integral to these resources. My hypothesis at this point of the research (end of the Exploratory phase) was that these specific features of science had the potential to be a common thread for the TLPs, connecting not only different examples of scientific development over time and societies, but also different lessons and resources, avoiding stand-alone and disconnected approaches within and among them. The importance of collaborative work for the development of new knowledge (including peer review processes and exchanges of ideas, data, instrumentation and materials) and the relationship between social-cultural-historical features of science and its epistemic dimension then guided the exploration of NOS aspects throughout the Implementation phase.

These explicit discussions about NOS were rooted in examples from different societies around the world (intercultural approach), highlighting the global aspects of scientific enterprise. It was expected that this strategy would enable more in-depth conversations about the social-cultural-historical aspects of scientific work, importance of technology and instrumentation to scientific development, exchanges of ideas, data, instruments, materials, among many other aspects of NOS that seem to be peripheral or inexistent in students' views about NOS, as identified in this Exploratory phase.

Chapter 6: Implementation phase – Developing and Teaching the teaching and learning plans (TLPs)

Throughout the Implementation phase, carried out at school A, I investigated the development, teaching and impact of teaching and learning plans (TLPs) that aimed to integrate NOS aspects into school science curricula with the aid of an intercultural approach to HOS, exploring RQ4 and its subset of questions:

RQ4. In which ways can an intercultural model of HOS be successfully integrated into school science through TLPs to foster teaching and learning of NOS?

> **RQ4.1.** How can the planning and teaching of these TLPs be carried out to promote the integration of NOS into school science?
>
> **RQ4.2.** In which ways can this approach impact students' understandings of NOS and what are their views about this experience?

This chapter then presents and analyses the main findings related to RQ4.1, focusing on two different dimensions of analysis: 'development' and 'teaching'. In section 6.1 I will analyse the former, exploring the development of the TLPs through my collaborative work with the participant teacher (teacher F), while section 6.2 will be dedicated to the 'teaching' dimension, involving the observations of his teaching of these TLPs to a year 8 group, and his impressions about the experience. Three themes developed as part of the analysis of the lessons observed during the Exploratory phase ('Drawing on examples'; 'Connecting knowledge with socio-scientific contexts and people's lives'; and 'Talking about science and its nature') will be especially useful in section 6.2, where they will be employed to describe and better understand what the intercultural model of HOS can bring to school science practices in terms of use of examples and integration of SSIs and NOS aspects with regular content.

6.1. Intercultural model of HOS and the development of TLPs

The development dimension encompassed a reflection about the process of creating the TLPs, with special attention to the affordances and constraints presented by the scholarship in the field of HOS, by the KS3 science curriculum and by the reality of the participant class to the incorporation of HOS/NOS into science lessons. This experience was then investigated in relation to: the selection of topics from this official curriculum to be transformed into TLPs; the production of the TLPs (considering both historical-epistemological and pedagogical perspectives); and my work with teacher F.

6.1.1. Selecting the topics – Medicines, Magnetism, Evolution and Earth's resources

Teacher F was very open to the topics from the KS3 curriculum that would be explored by the TLPs, even suggesting the inclusion of an extra one (Medicines) that was not part of the official scheme of work for year 8. In relation to the time available for teaching the TLPs, he mentioned that they followed a specific plan for the length of each topic at school A (around seven-eight single lessons each), but this was manageable as long as he had enough time to finish the planned topics before the end of each correspondent half-term (usually two topics per half-term).

The topic of Medicines was then the first to be explored by this investigation in the form of a TLP, and different pedagogical and historical-epistemological reasons can be ascribed to this selection. Among the pedagogical reasons there was teacher F's degree in Biology. According to some researchers (Evans & Tribble, 1986; Raudenbush et al., 1992; Çakiroglu et al., 2005), science teachers' perceived self-efficacy on teaching different topics is influenced, among other aspects, by their original disciplinary specialisation (e.g. Biology, Chemistry, Physics). I then assumed that working on a Biology-related topic would make teacher F more comfortable in his first contact with an approach that would introduce new ideas (e.g. NOS and intercultural narratives) into his regular practice.

Here it is important to reflect on how the topic of Medicines is presented by the KS3 scheme of work adopted at school A. According to it, the teaching of this topic should be done in two or three lessons (two or three hours) and encompass ideas related to drug trials and animal testing[89], a clear link with NOS aspects, such as

[89] The lesson goals for this topic are: "learn about the stages involved in the testing of a new drug"; "learn about why scientists test medical drugs on animals"; "learn about what can happen when testing goes wrong".

testing and trial, and ethical and financial aspects of science. Choosing Medicines as the first TLP could then ease the incorporation of a HOS/NOS-oriented perspective into teacher F's lessons, also placing him at a comfortable 'starting point'.

Another point taken into account when choosing this topic were the possibilities presented by the field of HOS in terms of historical scholarship about the development of knowledge about Medicines and appropriate contexts/examples to be explored in the lessons. The availability of sources about the history of medicines and drug development was of great importance to production of this TLP, since the aim of this study was not to carry out the historical research from scratch, but in fact to aid the 'translation' of this academic body of knowledge to science lessons. In this scenario, since Medicines and the whole field of medical knowledge, healing, and exploration and uses of natural resources (Natural History) have been extensively researched by Historians of Science (e.g. Harrison, 2010; Andrews, 2011; Sebastian, 2011), this choice of topic seemed promising.

The second TLP in this investigation was developed around the topic of Magnetism, a choice linked to my interest in exploring topics from different subjects (Biology, Chemistry and Physics) to diversify my dataset. In addition, this topic would introduce an extra level of challenge to teacher F, enabling me to analyse the impact of his subject specialism on our work with the TLPs and the affordances and constraints of the intercultural model to teaching outside original subject specialisms.

Furthermore, while the Medicines topic was explicitly connected with NOS aspects in the scheme of work followed by school A, this link was not clear for the Magnetism topic[90]. According to McComas (2008), empirical proposals and curricula available for teaching about NOS from historical perspectives tend to focus on some specific topics of school science, such as those involved in Newton's, Galileo's and Darwin's works, while other topics, such as Magnetism and Chemistry-related ones, seem to receive less attention from this type of research. This can restrict the possibilities for teachers to develop a long-term and integrated work with NOS and content and to establish connections among NOS ideas in different topics/moments of the school year (McComas, 2008). In this context, exploring a topic that was not explicitly linked to NOS discussions by the regular scheme of work could allow me to investigate the possibilities offered by the intercultural model to less explored scenarios in NOS teaching.

The challenge here would be then to bring together the scientific content about Magnetism and NOS aspects that are not an explicit part of the scheme of work

[90] The learning goals for this topic are: "describe how magnets interact"; "describe how magnetic field diagrams tell you about the direction and strength of a magnetic field"; "explain observations about navigation using the Earth's magnetic field".

followed by teacher F. In order to better accommodate this work with NOS aspects into the TLP, a total of four hours, instead of the original two hours proposed by the scheme of work, was allocated to the teaching of this TLP. Thus, school A's and teacher F's flexibility regarding the official curriculum was significant to the development of this TLP.

Similar to the case of Medicines, the historical scholarship about Magnetism (e.g. Mattis, 1981; Smith, 1992; Mottelay, 2008) also seemed promising to the development of this TLP under the intercultural model. It is important to highlight here, however, that this was only the case for ideas around magnetism, magnetic materials and magnetic fields. Diverse narratives specifically connected with electromagnetism were less easy to find since, in this case, HOS tends to draw mainly on developments during the nineteenth and twentieth centuries and on specific local accounts involving James Clerk Maxwell and Hans Christian Ørsted (e.g. Guisasola et al., 2005; Byrne, 2015). Therefore, considering the scholarship and time available for us to work on this TLP, a decision was made alongside teacher F to focus only on magnetism, magnetic materials and magnetic fields, leaving the topic of electromagnetism to be taught as suggested by their scheme of work at school A.

The third TLP was developed around another Biology topic – 'Evolution'. The main reason for this choice was related to it being usually explored through historical lenses by school science, with special attention to Charles Darwin's work (McComas, 2008), one of the few times when even less historically and philosophically informed practices incorporate some degree of HPS. Therefore, trying to include the intercultural model into a specific teaching tradition that is already informed by HOS would be interesting for this study, mainly due to the novel characteristics of the proposed historical view on this topic.

According to the scheme of work at school A, the teaching of Evolution should last around four lessons (four hours), encompassing[91]: the mechanism of Natural Selection, Charles Darwin, Extinction, and Preserving Biodiversity. Here it is important to remark how, while this scheme promotes some connections between this topic and NOS aspects (such as peer review process and the relationship between environment, science and humans), it does not propose talking about other ideas also closely connected to this theme, such as: scientific theories and explanation; evidence;

[91] The learning goals for this topic are: "describe the theory of natural selection"; "describe why species evolve over time"; "describe the process of peer review"; "evaluate the evidence that Darwin used to develop his theory of natural selection"; "state some factor that may lead to extinction"; "describe the importance of biodiversity in maintaining plant and animal populations"; "explain why a species has become extinct"; "explain how a lack of biodiversity can affect an ecosystem"; "explain what is meant by an endangered species"; "describe some techniques used to prevent extinction"; "describe how preserving biodiversity benefits humans".

controversies and disagreements in science; exploitation of natural resources; and financial and ethical aspects of science. The challenge here would be then to promote more explicit and in-depth discussions about different NOS aspects during the expected four lessons (four hours) about this topic.

The last topic to be explored during this phase was ‘Earth’s resources’. This choice was initially made to ensure that a Chemistry-related topic would be part of the study and because teacher F had mentioned at the beginning of the school year that this was the subject he was the least comfortable with. Working on a TLP from a subject outside teacher F’s specialism and comfort zone would enable me, as argued before, to deepen my analysis of the possibilities and hindrances of the approach proposed here.

In addition, exploring this topic would also be relevant to this investigation due to the low number of proposals available in the Science Education field around the inclusion of NOS aspects into Chemistry lessons (McComas, 2008; Chamizo & Garritz, 2014) and its teaching often “isolated from everyday life and society, HPS, technology and chemical research” (Chamizo & Garritz, 2014, p. 357). In this scenario, our work with this TLP could offer an insight into how NOS aspects involved in the development of chemical knowledge and technology can be made explicit in Chemistry lessons.

According to school A’s scheme of work, this topic should be covered in two lessons (two hours) around ‘Extracting metals’ and ‘Recycling’. From its learning goals[92], we can see a clear focus on technical chemical knowledge (illustrated by “state”, “recall” and “describe”) involved in memorising methods, definitions and procedures, with less attention paid to some SSIs and NOS aspects, such as the relationship between science, technology, environment, ethics and sustainability. Here my proposal was to bring these ideas and discussions to Chemistry lessons that seem to be still mainly concerned with memory-based and procedural chemical knowledge, trying to include a more critical dimension into the analysis of this body of knowledge.

On the positive side, contemporary research in the field of SSIs (e.g. Ratcliffe & Grace, 2003; Levinson, 2006; Sadler, 2011) and on the History of environmental studies (e.g. Castree et al., 2018) has been productive in recent years, and they could offer ideas of examples/cases to be explored in this TLP. Furthermore, the field of HOS has been recently taking a more post/decolonial approach to the study of the use of natural resources (e.g. Silva, 2004; Gandolfi & Figueiroa, 2016) and, especially in the

[92] The learning goals for this topic are: “state what an ore is”; “recall the methods of extracting metals”; “describe how the Earth’s resources are extracted”; “justify the choice of extraction method for a metal, given data about reactivity”; “suggest factors to consider when extracting metals”; “state why certain natural resources will run out”; “explain why recycling some materials is particularly important”; “describe how Earth’s resources are recycled”.

case of mineral exploitation, this scholarship tends to adopt a more global perspective, considering, for instance, the material and intellectual exchanges between colonies and colonisers.

In the end, four different topics (Medicines, Magnetism, Evolution and Earth's resources) were explored throughout this Implementation phase (one topic per half-term), informing my analysis of the affordances and obstacles for working with NOS aspects alongside regular content from an intercultural perspective. The choice of diversifying the topics enabled me to make comparisons between my findings, to investigate how the intercultural model of HOS could be adapted to different TLPs, and to establish the iterative cycle of 'planning', 'implementing' and 'evaluating' mentioned in chapter 4.

6.1.2. Developing the topics into TLPs: Global History, NOS, content and collaborative work

Following the choice of topics for the TLPs, this study continued with the development of these resources. A general criticism of proposals to school science using HOS is that they often focus on historical-philosophical ideas, with only some generic insights for teaching, that is, of pedagogical nature (Besson, 2014). Therefore, in this study, the production of the TLPs involved two types of work: historical-epistemological and pedagogical (Forato et al., 2012).

The historical-epistemological stage consisted of the analysis of the scholarship from the field of HOS, including primary and secondary sources, under a 'Global History' perspective (Roberts, 2009; Elshakry, 2010; Fan, 2012). This work was grounded on views of scientific knowledge as a product of exchanges and collaborations between different cultures, and of the circulation of diverse types of knowledge around the world, all promoted by historical and geographical contexts, focusing on:

- Medicines TLP: accounts about the history of medicines, medical knowledge and uses of natural resources (Natural History);
- Magnetism TLP: history of the relationship between science and technology, material sciences, maritime travels, mining and Earth's magnetic field;
- Evolution TLP: historical and cultural narratives around the processes of species change, collection of evidence and development of explanations for these processes around the world, historical relationship between naturalist travels, natural resources, extinction and the development of the theory of Evolution;
- Earth's resources: accounts about the history metal usage/exploitation in different

societies, and about the relationship between these natural resources, environment, recycling and chemical knowledge and technology around the world.

The goal at this stage was to collect historical information about the uses of medicines, accounts and uses of magnetism, and the development of ideas related to evolution and extinction of species and about metal exploitation by different cultures around the world, dedicating special attention to the movement of knowledge and materials between diverse places throughout history. It is important to remark here, however, that the historical research carried out at this moment was not an easy task, especially in the case of Medicines and Evolution. Despite my previous training in the field of HPSS and my experience in working with primary historical sources, the intercultural nature of my approach towards HOS exposed how this field is still grasping with the Global History model, as illustrated by the scholarship on electromagnetism mentioned in the previous subsection.

Similarly, even if the historical scholarship about Medicines and the theory of Evolution can be considered well developed and abundant, they still lack this global perspective. Most of the historical narratives in the field still look at knowledge development about Medicines at local levels, as a product of specific processes in a particular nation or civilisation, not focusing on the “transmission, exchange, and circulation of knowledge, skills, and material objects” (Fan, 2012, p. 251). Likewise, most historical accounts about ideas on the evolution of species focus mainly on modern works by well-known scientists like Lamarck, Darwin and Wallace, with less attention being paid to other narratives and ideas on evolution coming from other communities. More importantly, few researchers in this field (e.g. Bourguet et al., 2003; Murphy, 2007; Harrison, 2010) look at how the seventeenth, eighteenth and nineteenth centuries naturalist travels and other mechanisms of knowledge exchange with non-European communities possibly influenced ideas about biodiversity and evolution.

Therefore, part of my work with these two TLPs involved the construction of intercultural narratives. For the Medicines TLP, my aim was to highlight, among other things, the importance of natural resources to the use of medicines, how native and local knowledge about these resources were employed by specific cultures, and how the frequent contacts between different groups enabled exchanges, collaborations, adaptation and exploitation of this expertise. This encompassed research on practices and knowledge about medicines in Native American, African, Arabic and Asian traditions, and on the processes of expansion of different communities, including the Europeans, through maritime and land route travels (such as the Silk Road and the

Great Navigations), commerce, forced migration (diasporas, slavery), colonisation, anthropological and naturalist travels, among others.[93]

In the Evolution TLP, I opted to connect the ideas around natural resources, biodiversity and naturalist travels previously explored by Medicines TLP with the narrative behind the development of the theory of Evolution, with the explanation behind the mechanism of Natural Selection and with biodiversity. The main narrative was then about the construction of these ideas and explanations about why species are so different around the world, why they are constantly changing, and the impact of human activity and exploitation of natural resources on these species[94].

In the case of the Magnetism and Earth's resources TLPs, the work under a Global History perspective was partially less problematic, since an extensive part of the HOS field dealing with these topics is grounded on discussions about knowledge and material exchange and expansion. This seems to be related to the fact that part of the history about magnetism is connected with the development of the compass and its uses for navigation purposes. In this scenario, more scholarship is available regarding how this initial use of magnetic properties (also done by others, such as Greek, Indian and Islamic communities) was exchanged and expanded by the interactions between different groups, and how it enabled even more expansion and contact between communities through technological innovations.[95]

Similarly, recent scholarship about the history of mineral exploitation has started to take into account the impact of naturalist travels on the development of chemical and technological knowledge about metals, extraction techniques, and environmental concerns, as argued in the previous subsection. That is the case, for instance, of research into the colonies in the Americas and their work around metallurgy during the sixteenth, seventeenth and eighteenth centuries, and into the techniques of metal manufacturing in Africa, Asia and Middle-East and their expansion to Europe.[96]

This study on the historical and intercultural complexity behind the development of knowledge about medicines, magnetism, evolution and earth's resources generated a large amount of information on these topics, including different examples and historical cases from different places and cultures. The next stage in this experience was then of a pedagogical nature (Forato et al., 2012; Besson, 2014), involving the

[93] Some references consulted during this process: Crellin (2004); Harrison (2010); Anderson (2013); Cook & Walker (2013); Sewell & Rafieian-Kopaei (2014); Yuan et al. (2016); Wellcome (n.d.).

[94] Some references consulted during this process: Ley (1968); Bowler (1989); Schmitt (2009); Domingues & Sá (2011); Duarte (2013); Darwin Correspondence Project (n.d.).

[95] Some references consulted during this process: Needham (1962); Mattis (1988); Smith (1992); Johnson & Nurminen (2007).

[96] Some references consulted during this process: Silva (2004); Pataca (2006); Alvim & Figueiroa (2007); Smith (2011); Klem & Klem (2013); Barles (2014); Gandolfi & Figueiroa (2016).

creation of a more simplified but still historically accurate and meaningful account of this global HOS to inform the TLPs.

Transforming historical scholarship into a school science TLP is not a simple or straightforward process, as discussed by others in the field of HOS and Science Education (Höttecke & Silva, 2011; Forato et al., 2012; Rudge et al., 2014). Some of the challenges faced here were: selecting the NOS aspects to be presented; selecting the historical cases to be used in the lessons; the level of non-scientific detail/context to be provided ('oversimplification'); language differences between historical accounts and students; among others. To overcome these obstacles, recommendations from similar empirical experiences found in the field [especially the works by Höttecke and Silva (2011) and Forato and colleagues (2012, p. 677-678)] were followed at the initial stage of development of the TLPs, such as:

a) Establishing from the beginning the targeted teaching purposes (content and NOS) for the TLP as a whole and for each lesson, task and discussion proposed.
b) Choosing the aspects to emphasize or omit from each historical context according to the NOS aspects to be explored in the TLP.
c) Mediating the possibility of oversimplifications and omissions, both in terms of scientific and historical aspects.
d) Circumventing the lack of student's prerequisites regarding their mathematical, physical, historical, philosophical or epistemological knowledge.
e) Presenting different examples from different cultural/historical contexts to promote connections and comparisons (about content and NOS).
f) Choosing to address issues that arouse the curiosity of this age group. The texts and activities should be able to promote the students' interaction with the issue.

Items (a) and (b) from this list of pedagogical suggestions were approached interconnectedly, through looking at the main NOS aspects that could emerge from an intercultural approach to the topic. After considering the possibilities from the HOS scholarship, NOS aspects were selected (as seen in table 8 below), and then informed the process of adapting historical accounts into an intercultural narrative that would enable teacher F to address these aspects explicitly. This creation of an intercultural narrative for the lessons then allowed the TLPs to emphasise the circulation and exchange of knowledge related to the topic, instead of focusing solely on some specific and disconnected cases from HOS.

Table 8. NOS aspects explored in each TLP

TLP			
Medicines	*Magnetism*	*Evolution*	*Earth's resources*
Social and cultural influences and controversies in the production of scientific knowledge	The relationship (and differences) between Science and Technology	Collaborative and collective nature of the scientific work	Collaborative and collective nature of the scientific work
The importance of natural resources for the production of scientific knowledge and the consequences of their exploration (including environmental issues and intellectual property in science)	The importance of observation and indirect evidence in Science	The role of controversies, disagreements and processes of certification (peer review) in science	The relationship (and differences) between Science and Technology
Collaborative and collective nature of the scientific work	Social and cultural aspects of science (commercial aims, contextual influences, exchange and transmission of knowledge)	The concept and use of evidence in science	Social and cultural aspects of science (commercial aims, contextual influences, exchange and transmission of knowledge)
Relationships between science, ethics, economy, politics, etc.	Science is tentative, creative and does not answer all the questions	The relationship between evidence, explanation and theory	The relationship between natural resources and science
Scientific claims through evidence and testimony	The role of modelling in science	The relationship between science, ethics, economics, environment, etc.	The relationship between science, ethics, economics, environment, etc.
The role of experiment, controlled investigation and quality control in science		Social and cultural influences in the production of scientific knowledge	Science is tentative, creative and does not answer all the questions

Let us take, for instance, the Magnetism TLP; the main learning goals from the scheme of work adopted by school A, as already mentioned in the previous subsection, were: “describe how magnets interact”; “describe how magnetic field diagrams tell you about the direction and strength of a magnetic field”; “explain observations about navigation using the Earth’s magnetic field”. So this TLP teaching purposes [item (a)] would necessarily be to cover this content, while also exploring some relevant NOS aspects behind the development of knowledge about magnetic properties and magnetism. And this is where the previous historical-epistemological research comes into play: by having researched historical accounts about uses of magnetic materials and knowledge development about this phenomenon in different cultures/societies throughout our history, I was able to bring several examples that could be employed in the lessons to my pre-teaching meetings with teacher F. These were, for instance: ancient Greek descriptions of the ‘attracting’ properties of lodestone; use of magnetic stones by Indian communities to perform medical procedures; the invention and use of the compass by the Chinese; the use of compass by Middle-East communities for navigation; and studies about the Earth’s magnetic field.

The next stage would be then to identify which relevant aspects of NOS these examples would enable us to cover in the TLP [item (b)], having in mind our goal of approaching these through an intercultural perspective, that is, by examining exchanges and circulation of knowledge, materials and instruments related to magnetism. This work then initially involved the organisation of these different examples into a narrative that would explore knowledge development about magnetism based on what we know, in the field of HOS, about how these exchanges took place. Table 8 above summarises the NOS aspects that emerged from an intercultural look at the examples around the topic of magnetism found in the HOS scholarship.

An illustration of this link between NOS aspects and the adoption of an intercultural look at the accounts about magnetism in the HOS can be seen in figure 19 below. This is a specific section of lesson 2, where teacher F would start by discussing how magnets interact (attraction and repulsion, North and South poles) and then introduce a conversation about how this is related to the compass (an instrument already employed in lesson 1 as an example of use of magnetic properties by the Chinese). The plan was to follow that up with an exploration of the spread of this instrument (and knowledge about it) from China to the European world, leading to innovations in navigation, and culminating in a task (in pairs) that would ask his students to think about the impact of this type of technological development on different sectors (politics, economy, everyday life, and science and technology).

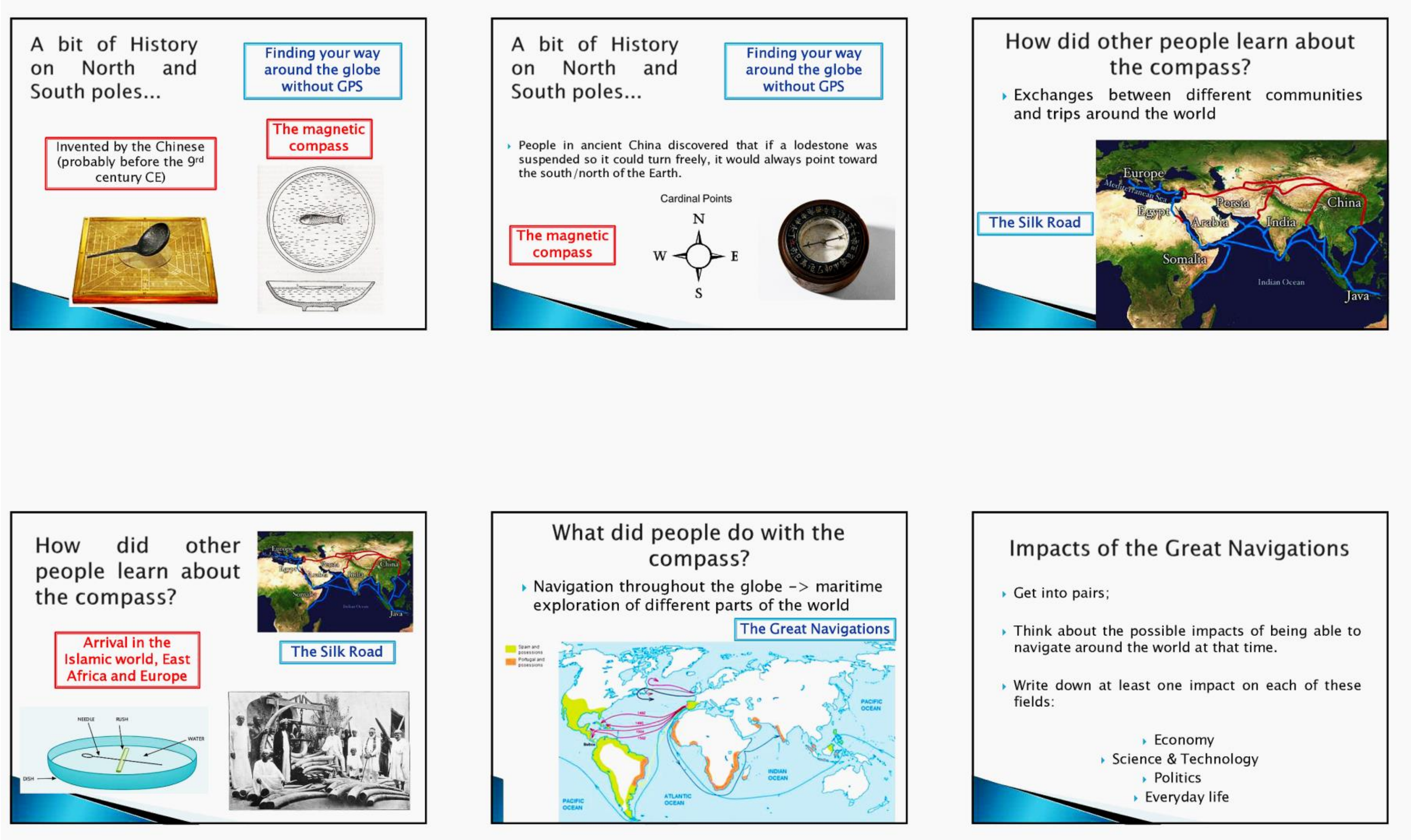


Figure 19. Sequence of slides used in lesson 2 of the Magnetism TLP

This specific section of lesson 2 would then involve discussions about different social and cultural aspects of scientific work and communities, such as: commercial and political aims of technological/scientific development; material and knowledge exchanges; and relationship between science and technology. Meanwhile, original content expected by school A's scheme of work for the magnetism topic would also be explored here, since this lesson 2 would start by looking into "how magnets interact" and then use this historical exploration of the compass to ground, during lesson 3, the goal of explaining "observations about navigation using the Earth's magnetic field".

Beyond deciding on the main narrative that would inform the logic behind the TLP and identifying teaching purposes in terms of content and NOS aspects, this development stage also involved making historical selections and adaptations of the examples and stories that would be incorporated into the resources. Items (c), (d) and (f), related to the impact of these selections and adaptations on students' understandings of historical and NOS elements and on their participation in the lessons, were then addressed by an engagement with their own ideas through the careful planning of whole class discussions and follow-up questions. These questions were created in an 'assessment for learning' perspective (Black & Harrison, 2004), not aiming to check students' knowledge about NOS in a declarative way, but to promote rich discussions that would involve different possible perspectives raised by the students about these topics. The aim here was to not solely listen to responses, but to listen for their reasoning in developing these responses (Cowie et al., 2018). In addition, the use of this question-answer strategy can also promote an explicit work with NOS aspects, which, as argued in chapter 2, seems to offer more positive results for students' learning about NOS than an implicit approach (Deng et al., 2011).

Going back to the Magnetism TLP, this strategy can be illustrated by how teacher F guided the aforementioned discussion about the Earth's magnetic field during lesson 3, connecting it with previous discussions about the compass (from lesson 2). After talking about William Gilbert's work on this phenomenon, the plan was to ask students to think about the following questions:

1. So, can you explain now why do the compasses developed a long time ago by the Chinese work so well?

2. What do we mean by "model of the Earth's magnetic field"? What do we mean by model?

3. Did Gilbert carry out his experiment with the Earth itself? How did he model the Earth in his experiment?

4. Think about how Gilbert found out about the Earth's magnetic field. Can he (or we) see this magnetic field? How does he know that this field exists then?

Another example, now from the Medicines TLP, also illustrates this approach. In an assignment where students were asked to choose from herbal or conventional medicines and then present their case to the rest of the class, planned follow-up questions involved:

1. What is the difference between natural and artificial medicines?
2. How do we know if the remedies are effective?
3. Is there enough information on the sheets to make informed decisions? What else would you need?
4. How do you think scientists go about collecting evidence to evaluate these remedies? Is having evidence enough to convince other scientists and people in general about a scientific idea? What else do they need?
5. How do you think scientists work with these natural resources? How do you think they go about transforming them into artificial medicines?

In the case of the Evolution TLP, the use of follow-up questions can be exemplified by the set of questions below, asked by teacher F to his students during their work on an assignment about society's and scientific community's reception of Darwin's works on natural selection and the theory of Evolution:

1. Which comments were presented by religious critics?
2. Darwin was a religious person and was very concerned about the implications of this work to religious views. Do you think public opinion should be taken into account by scientists? Why?
3. Which positive comments were made by scientists? Do you agree with them? Why?
4. Which negative comments were made by scientists?
5. Scientists sometimes criticise each other's works, like some did with Darwin and Wallace. Do you think this is a good or a bad thing? Why?

Similarly, the set of questions below informed small group and whole-class discussions during students' work on different examples around the historical uses and exploitations of metals around the world, as part of the Earth's resources TLP:

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 to humankind?
4. What is the relationship between using metals, Science and Technology? Think about the examples in your cards.
5. How were the metals obtained by the communities in your cards? That is, where did (and still do) they mostly come from?
6. Do you think all metals can be found in all places around the world?

These questions were then employed to generate explicit scaffolding discussions about NOS from students' answers and reasoning, instead of being used by teacher F to simply check their comments as right or wrong (Black & Harrison, 2004; Cowie et al., 2018). As argued by others (Schwartz & Crawford, 2004; Clough, 2006; 2008; Martins & Ryder, 2015), this explicit, question-based and reflective approach to lessons involving NOS helps teachers and material developers not only to overcome issues related to oversimplifications and previous knowledge, but also to promote an integration of sociological and historical themes into content-based science lessons.

The use of assessment for learning strategies would, however, demand a high degree of responsiveness and openness so teacher F could simultaneously carry out the specific discussions about NOS ('convergent formative assessment') and address unexpected and 'on-the-fly' answers/ideas from his students ('divergent formative assessment') (Cowie et al., 2018). As discussed previously in my analysis of the Exploratory phase and its theme 'Interacting with students' knowledge and interests', while teacher F was open to his students' ideas, we cannot ignore the complexity of using assessment for learning strategies to stimulate more in-depth classroom discussions (as opposed to simply acknowledging students' contributions and moving on with the lesson). In section 6.2, the impact of this approach on the teaching of the TLPs and on teacher F's impressions about it will be specifically addressed.

Lastly, item (e) was explored through an overlap within and between different TLPs (a spiral approach), with the same NOS aspects being part of different lessons and topics (as seen in table 8). This spiral approach was developed here through a mix between 'storyline' and 'integrated' strategies (Matthews, 1994). The 'storyline' strategy plans the teaching of a specific scientific content (e.g. Magnetism) under a "framework onto which a science topic […] can be placed in a developing narrative" (Matthews, 1994, p. 71), which enables constant reflections, comparisons and re-work on different NOS aspects as the narrative advances. Looking again at the Magnetism TLP, this approach was employed, for instance, to connect William Gilbert's work and knowledge development about Earth's magnetic field in lesson 3 with discussions had about the compass, North and South poles and navigation in lesson 2 (seen in figure 19).

Meanwhile, the 'integrated' strategy organises a whole science course on historical grounds, that is, it understands and plans the teaching of different topics under a similar historical-epistemological approach (Matthews, 1994), linking different narratives (TLPs) through shared historical and social backgrounds. Here, we can use the Magnetism and the Medicines TLPs as an example: the same discussion about knowledge and material exchange around the compass had already been explored in lesson 1 of the Medicines topic in relation to access to natural resources and its impact on the development of medicinal drugs, as seen in figure 20 below.

Figure 20. Sequence of slides used in lesson 1 of the Medicines TLP

This mix between ‘storyline’ and ‘integrated’ strategies then informed the construction of a spiral approach to these TLPs, which ended up connecting different science topics through similar historical-epistemological narratives that were linked by the intercultural model. Here it is worth noticing how the very nature of this intercultural perspective of HOS, which looks at scientific development from an integrated and global perspective, bringing different content and storylines together, seems to be closely connected with this proposed ‘spiral’ approach, thus addressing the pedagogical suggestion in item (e) and being one of the main affordances of this model identified throughout this study.

Another pedagogical challenge involved in the development of these TLPs was the integration of these historically accurate and meaningful discussions about HOS/NOS with the content expected by the schemes of work at school A. As argued throughout this project and by others in the field (e.g. Clough, 2006; 2011; Taber, 2008; Toplis, 2011), an integrated work between NOS and content can circumvent traditional obstacles in the implementation of innovative practices in science lessons, such as time constraints and teacher’s lack of knowledge about NOS.

The explicit, contextualised and question-based approach to NOS adopted in development of these TLPs was important to the promotion of this connection between NOS aspects and scientific concepts. By actively talking about these NOS elements through a historical strategy, content was treated as part of a process of knowledge production that happens in different contexts and through exchanges and collaborations, thus becoming a natural component of the lessons. This can be seen, for instance, in the examples discussed above for the Magnetism TLP: the exploration of the original learning goals for this topic (“describe how magnets interact”; “describe how magnetic field diagrams tell you about the direction and strength of a magnetic field”; and “explain observations about navigation using the Earth’s magnetic field”) was intrinsically connected with the historical narrative informing this TLP and with its NOS aspects, summarised by the link between how magnets work, the development and use of the compass for navigation and Earth’s magnetic field.

Results from my Exploratory phase were also relevant in this integration between NOS and content, since they aided the development of TLPs based on the processes of curriculum enactment (Ball & Cohen, 1996) carried out by different science teachers observed in the first stage of this study. Through observations during the Exploratory phase, I was able to take into consideration while planning the TLPs how these contents are usually taught, practices normally preferred by the teachers, interesting tasks and discussions carried out in relation to NOS, and students’ engagement with the lessons and topics.

This previous close engagement with teacher F's reality, personal resources and preferences also allowed me to avoid a high degree of 'incongruence' (Brown & Edelson, 1998; Janssen et al., 2013) between the activities and discussions proposed in the TLPs and his regular practice. While the TLPs were generally different from teacher F's lessons in terms of content, they also incorporated some aspects of his regular pedagogical strategies explored in chapter 5, such as openness to interactions with students, use of different examples and some in-depth discussions.

The use of a question-answer approach is an example of the influence of these observations of teacher F's lessons on the development of the TLPs. While addressing some pedagogical suggestions about integrating HOS into school science, this strategy was also chosen due to teacher F's interest in talking and discussing ideas with students during his lessons. Contrary to other teachers observed in the Exploratory phase who tended to favour experiments (like teacher B) or exposition (like teacher A), teacher F mentioned during our pre-teaching meetings his preference for developing his lessons around discussions about an example or idea.

Here it is important to highlight that my work with teacher F throughout this Implementation phase was also of great importance to the development of the TLPs, especially to the connection between NOS aspects and content. This collaboration, which involved a constant exchange of pedagogical ideas from his part and historical scholarship from my side, aimed at generating TLPs that would integrate NOS into regular science lessons more naturally and without losing sight of the curricular goals for each topic. Starting from my work in creating historical narratives and selecting relevant examples about the topic (the historical-epistemological stage), we would then move onto the pedagogical stage, which consisted of identifying possible ways to organise these narratives and examples into specific sequences of activities and discussions, while also employing different pedagogical strategies (e.g. peer work, discussions, exposition, and experiments).

At the end of a pre-teaching collaborative stage (one per topic), each TLP consisted of a lesson plan, a set of slides to be used during the lessons, and materials/guides/hand-outs for the proposed tasks/activities/homework. The TLP on Medicines was expected to last a total of four lessons (four hours), each one revolving around a core idea (lesson 1: natural resources and medicines; lesson 2: artificial drug development and biodiversity; lesson 3: drug testing; lesson 4: vaccines), as seen in appendix 17. The TLP on Magnetism was also expected to last four lessons, with the first two lessons involving the discussions about magnetic properties and magnetism, and the remaining two lessons about magnetic fields, as seen in appendix 18. Similarly, the TLPs on Evolution (lesson 1: the development of ideas about evolution and natural selection; lesson 2: the implications of the theory of Evolution to science and society; lesson 3: extinction; lesson 4: biodiversity) and on Earth's resources (lesson 1: Earth's composition; lesson 2: metal extraction I; lesson 3: metal extraction II; lesson 4: recycling) were also expected to last four lessons each, as seen, respectively, in appendices 19 and 20.

Nevertheless, the idea behind this collaborative pre-teaching stage was not only related to teacher F's professional input on how the organise these TLPs. I also expected to use these moments to promote an approximation between him and the aims of my investigation and the ideas proposed, instead of adopting a 'top-down' approach to the development of new teaching resources (Höttecke & Silva, 2011; Henke & Höttecke, 2015). According to Brown and Edelson (1998, p. 6):

> […] teachers must also possess a 'big picture' view of the investigation, understanding how the given task fits in with the overall curricular goals. The ability of teachers to understand and communicate short and long term learning goals, to manage both short term and ongoing tasks simultaneously, and to situate classroom activities within a larger instructional context facilitates both curriculum planning and student engagement.

In order to achieve this position where teachers see the 'big picture' behind innovative ideas, taking ownership of their work with these ideas, Ball and Cohen (1996) talk about the importance of understanding new teaching resources as opportunities for teachers' learning, that is, for professional development promoted by becoming involved in the production of these materials. Therefore, the pre-teaching meetings carried out throughout the development of the TLPs were also intended as moments for teacher F's professional development, both in terms of content (especially important for his perceived self-efficacy regarding Physics and Chemistry topics) and HOS/NOS knowledge, and in relation to different pedagogical approaches (Roblin et al., 2018), as further discussed in the next subsection.

6.1.3. Working with the teacher: talking about HOS, NOS and pedagogical strategies

The pre-teaching meetings with teacher F were carried out on two different days (totalling around four hours) prior to the start of the teaching of each TLP. As mentioned in the previous subsection, these meetings involved discussions about HOS, NOS and pedagogical strategies that would be transformed into a TLP. They were then used both as development moments for these TLPs and as learning moments for teacher F, especially about HOS and NOS.

During the first pre-teaching meeting, I presented suggestions of examples from HOS (e.g. historical accounts involving magnetism, magnetic materials and instruments) and NOS aspects that could be possibly explored in the TLP, and a subsequent discussion was carried out about tasks and talks that could be developed throughout these lessons to address both these NOS aspects and the expected content. This initial talk then aimed to not only share suggestions for examples, discussions and general organisation of the TLP (including teacher F's view on what would and would not work with the participant class) – the procedural dimension (Roblin et al., 2018) –, but also to familiarise him with the main historical-epistemological ideas behind the TLP – the educational dimension (Roblin et al., 2018).

Among teacher F's procedural suggestions during this meeting there were: including extra scientific concepts in the TLPs (for Medicines, that was the case of discussing biodiversity and vaccines; for Magnetism, that was the case of talking about the origins of magnetic properties in different materials; for Earth's resources, that was the case of talking about precious metals); homework; pedagogical strategies (such as practicals in the Magnetism and Earth's resources TLPs); and activities/tasks (for instance, task 1 – 'Survival of the Fittest' in the Evolution TLP). After this meeting we would then work on the hand-outs for proposed tasks, slides for the lessons, and general organisation of all materials related to the TLPs, which would be further discussed at the second pre-teaching meeting.

This second meeting consisted of specific and in-depth work on historical-epistemological points that would be part of the TLP, with special attention paid to the slides to be used in the lessons to introduce the historical accounts, NOS aspects, scientific concepts, and tasks agreed upon during the first meeting. We then went through the slides together, and by doing that I was able to provide teacher F with an introduction to the more in-depth historical, philosophical and sociological aspects related to the TLP, and to answer any questions he might have about them. Additionally, we also focused on NOS aspects to be explored by the TLP and, more specifically, on the follow-up questions that would guide his conversations about NOS with the students.

Teacher F's expertise and personal knowledge about this group were a relevant part of this meeting, and his inputs were thoroughly considered in the process of reworking and finalising the TLPs before the teaching stage. Here, he particularly enjoyed the fact that most of the lessons would be guided by questioning, which he thought would make the whole process more interesting to this group of students, since they were already keen to ask and answer questions. It is worth remarking that while teacher F usually favoured this question-answer approach in his regular practice, he stated at these pre-teaching meetings that he was not used to having these questions planned beforehand. This pedagogical strategy would then introduce a new aspect to his lessons, being a relevant part of his professional learning (Ball & Cohen, 1996) throughout this experience, to be further analysed in section 6.2.

One of my specific concerns with these TLPs, especially with the first to be taught (Medicines), was the depth of some follow-up questions and tasks, since they would demand a high level of thinking about NOS that students might not have been used to, and a type of engagement with their teacher that would go beyond answering questions as ‘right’ or ‘wrong’ (Cowie et al., 2018). Two important teacher F’s suggestions here were: to not use too long questions on the slides, splitting and animating them to help students to understand what was being asked more easily; and to spread the different tasks throughout a lesson, instead of having them all at the beginning, otherwise students’ engagement could become uneven. Teacher F, however, assured me that he was confident that this group would be able to engage with the tasks and discussions about NOS we had been planning:

> Researcher: “I’ve seen your lessons [on Medicines] last year, but there are new things there, so **I don’t know if the level is too much**...”
> Teacher F: “No, **it will be fine, I’m sure**.”
> Researcher: “OK.”
> Teacher F: “Yeah, and if it’s not, we try it anyway, because some of the kids will get it. [...] But they’ll be fine. **I can teach them anything, you just have to scaffold for them you know**?”

In relation to the historical-epistemological guidance on HOS and NOS that I had offered him throughout these meetings, teacher F remarked that he was feeling comfortable about our work together and that he was learning a lot about science, NOS, subject content and about being creative in his lessons. Interestingly, during our preparatory meetings for the Magnetism TLP, he talked about how, in the past, he had specifically struggled with teaching this topic because he “had never learnt too much about it”. He highlighted how he thought his lessons about this concept were less creative and diverse than others, mainly due to his lack of confidence in using different materials and preparing extra activities beyond those proposed by the textbook:

> Teacher F: “So **magnetism is such a small, kind of like a throw way topic, that I’ve never learned it much in-depth myself**. Usually I have very little extra to add to magnetism lessons. **I reckon that I’ll probably learn more from this than I have to give to be honest**.”

> Researcher: "It doesn't seem that you don't know a lot about magnetism, I remember your lesson last year, the kids were very engaged."
>
> Teacher F: "Well, I know enough [...], but **with magnetism I feel like I probably teach this quite flat**."
>
> Researcher: "What do you mean by flat?"
>
> Teacher F: "I don't bring a lot of examples. **I don't find it necessarily boring, I just don't have anything else to tell them about it.**"

Therefore, he was hopeful that this TLP would give him more confidence about his work, since he was being stimulated to think about and work with different tasks and follow-up questions. Here, there is a clear impact of our collaborative work on his perceived self-efficacy (Roblin et al., 2018) about this topic, an aspect that I will also explore in section 6.2. In addition, as previously mentioned, it was also my interest to understand the possibilities offered by the intercultural model and by my close work with teacher F to his teaching of topics outside his subject specialism, so his first impressions about the Magnetism TLP seemed promising.

Additional comments about our work on these TLPs were made by teacher F during one of our pre-teaching meetings for the Earth's resources topic. He noted that, after working through the three previous topics, he was feeling confident that this TLP was going to work well for him despite Chemistry not being his specialism. According to him, his growing familiarity with discussions about NOS aspects and with the question-answer approach made him more comfortable with this type of lesson. Once again, it is worth noting here the effects of the learning opportunities for teacher F during this collaborative work on his perceived self-efficacy.

The last part of the historical-epistemological guidance offered to teacher F comprised written comments and links to extra materials about NOS and HOS related to each topic. The comments included the same discussions about HOS and NOS from the second pre-teaching meeting, and were produced to provide teacher F with readable explanations about the aims of each part of the lesson and comments on HOS and NOS that could further his learning from these TLPs (Roblin et al., 2018). These comments and links to extra materials were embedded in each slide and an example from the Medicines TLP can be seen in figure 21.

During our meeting about this TLP, teacher F highlighted he was planning to add these materials (slides, lesson plan, and hand-outs) and all the future TLPs to an online folder shared by the teachers in the Science Department at school A because they were complete with comments and explanations, which would make it easier for others to use them. He stressed that many teachers would be able to benefit from these TLPs and, more generally, from the way all the TLPs were being constructed, which, according to him, brings 'context' to the teaching:

> Researcher: "Can you tell me a little bit about what happened [in his meeting with the other teachers from the science department]?"
>
> Teacher F: "Yes, so **each week we do like a teaching and learning briefing**, which is about 10 minutes long, and it was my turn last week. **So I shared what we've been doing, I showed them the magnetism lessons, I showed them the format of the lessons, and I showed them the actual slides. And they were really interested in this idea of stories, and context in that perspective rather than application of this context**."

According to Henke and Höttecke (2015) and Roblin and colleagues (2018), these learning moments involved in teachers' work with curricular materials can impact not only their perceived self-efficacy about a specific content, but also their own views about science, NOS, and regular pedagogical strategies, while also influencing their students' learning and engagement with the lessons. The effects of this pedagogical and historical-epistemological collaborative work (Roblin et al., 2018) with teacher F on his lessons about Medicines, Magnetism, Evolution and Earth's resources will be then further analysed in the next section.

- Talk about how knowledge about medicines from different cultures (for instance the willow tree bark and the Amazonian viper) were shared and collected throughout the centuries by people travelling around the world.

- Exemplify that by talking about the Silk Road, an ancient network of trade routes that ran from China through India and Persia, arriving in Africa and south Europe (now Turkey – Istanbul). It was the centre of commerce between these communities between around 120BCE until 1450CE (remember Marco Polo), when the Great Navigations expanded other sea routes and contacts with the Americas (next slide about Great Navigations). It was through this route that most of Chinese and Indian traditional medicine arrived in Europe, alongside Islamic and African knowledge.

- Same idea from last slide, now exemplifying the new trade and colonisation routes created by the Great Navigations – also known as the "Age of Discovery" or the "Age of Exploration" (exploration of African Atlantic coast starts with the English and Portuguese in early 1400s; then the Indian Ocean in 1488, culminating with Christopher Columbus landing in the Americas in 1492).

- Highlight that the expansion of European domains also expanded scientific knowledge, specially in the fields of Zoology and Botany (new species), helping the creating of new medicines. Most of this knowledge is acquired through the contact with the native people in these new lands.

- Highlight the collective aspect of scientific knowledge, how it's more than just 5 or 10 people working on a specific topic, but in fact the culmination of years of knowledge exchange between different communities/traditions, and that not everybody is always recognised by their contributions (until nowadays) -> think about why that's the case.

Figure 21. Example of slides used in the Medicines TLP (with written guidance for the teacher)

6.2. Teaching with the intercultural model of HOS: a view from the classroom

Following the development of the TLPs, the second stage of this investigation encompassed the teaching of these topics by teacher F. Two dimensions of this stage are considered here: teaching the topic – i.e. how the lessons were taught (informed by themes generated through my observations during the Exploratory phase and presented in chapter 5) and possible changes and transformations made by teacher F during this process; and teacher's impressions about the teaching experience – including discussions about time and pedagogical constraints, students' engagement, and personal perspectives such as comfort with HOS and NOS teaching and with the intercultural model of HOS.

6.2.1. Teaching with the TLPs

An outline of the lesson observations

The teaching of the TLPs was carried out by teacher F at his year 8 class and followed the ideas proposed in appendices 17, 18, 19 and 20. Data about this stage of the investigation was generated through audio-recordings of teacher F during his lessons and my field notes as a participant observer. The analysis of these observations was inspired mainly by three themes explored in my Exploratory phase: 'Drawing on examples', 'Connecting knowledge with socio-scientific contexts and people's lives', and 'Talking about science and its nature'.

Teacher F's use of examples during the Medicines TLP can be considered varied, encompassing discussions about specific items (such as examples of industrialised and natural medicines bought in famous high street shops in England, or examples of natural resources used by Indian and Native American communities as medicines), and about historical or contemporary cases (such as the thalidomide case or the relevance of the Silk Road and Great Navigations to the construction of knowledge about natural resources and medicines). This situation is not very different from his lessons on Medicines observed in the previous year, when he was also seen employing assorted examples.

A significant difference regarding the types of examples, when compared with my Exploratory phase, was seen in his new lessons on Magnetism. His previous work around this content focused on reading about magnetism and magnetic materials from the textbook, with more attention paid to explanations of scientific concepts than to examples of any kind. When some specific items were in fact employed to talk about magnetism, they were mainly related to everyday life objects (such as fridge magnets), with less focus on historical, social or large-scale scenarios. Conversely, his lessons informed by this TLP introduced students to a large variety of examples, ranging from these everyday life objects to other historical and contemporary items (such as the compass, surgical instruments and medical equipment, and maglev trains), as well as historical cases (such as links between different civilisations' works with magnetism, the development of the compass and the Great Navigations, or William Gilbert's and Mary Somerville's works on, respectively, Earth's and light's magnetic properties).

Similarly, the teaching of the Evolution TLP also encompassed a good variety of examples, ranging from specific items (such as different species of animals and plants, or different historical ideas about the evolution of these species) to historical and more contemporary cases (such as Darwin's and Wallace's travels, Mary Anning's fossil collections, Nazi experiments with humans and ideas on eugenics and race, and preservation of blue macaws). Since this was the first time this topic was being taught as part of the KS3 scheme of work at school A, comparisons between examples can only be made regarding the original scheme of work. A brief look at this material shows that very few species are used to introduce ideas about evolution (such as peppered moths and finches), extinction (such as the dodo and the mammoth) and preservation of biodiversity (such as the black rhino and pandas), and while Darwin's works are also explored, the same cannot be said about other ideas on evolution. Teacher F's lessons on Evolution were then more diverse and richer in terms of examples and ideas presented to students when compared to the original scheme of work, which tended to focus more on explaining the content.

The lessons on Earth's resources, which had not been previously part of the year 8 curriculum followed at school A, also included a wide range of examples, from specific items (e.g. precious metals and their particularities; periodic table, classification and properties of specific elements) to historical and contemporary cases (e.g. accounts about the exploitation of different metals such as gold, thallium, and aluminium; development of extraction methods in Africa and India; the history of waste management and its different milestones). In comparison, their original scheme of work focused more on definitions of chemical concepts and procedures (e.g. ore, mineral, extraction) than on presenting and discussing different examples related to this topic (some exceptions were: bauxite as an example of ore; quantitative information about waste generated by iron extraction; tin cans as an example of a recyclable object).

Another difference between this experience and the lessons observed during my Exploratory phase is related to how examples were used by teacher F. In the analysis of that first phase, I discussed how participant teachers did not often propose a more contextualised or in-depth conversation about the examples being employed during the lessons, arguing for the need of more cases like these, especially if we aim to work with NOS aspects in school science.

Even though his original lessons on Medicines included a good variety of examples, with this new TLP teacher F dedicated more time to in-depth discussions than he had done in the previous school year, aided mainly by the use of the follow-up questions planned during the development stage described in section 6.1. In their first homework, for instance, students were asked to research about an herbal medicine: how it is/was used by a different culture, and if and how it is used as a source of active ingredient in conventional (commercial) medicines. Among the examples brought by them in the following lesson (lesson 2) there were: bark from mahogany trees to fight malaria in Ghana; ginger to cure nausea and as anti-bactericidal in India; Indian snakeroot for high blood pressure; mushroom tea for skin rashes in Kosovo. When presenting this homework, students were then stimulated by teacher F, through some planned follow-up questions[97], to think more deeply about these examples (and 'in-depth' approach):

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

It is worth noting how this more in-depth approach to the examples students had brought to the lesson led to discussions about environmental issues around the exploitation of natural resources and the production of conventional (commercial)

[97] 1. Is the knowledge about plants and medicines restricted to one specific place in the world?; 2. How do you think this knowledge was spread to other parts?; 3. Do you think this is good? Why? Is there any bad side to that?

medicines, including aspects related to biodiversity and the exploration of the land. It is also worth noticing how student B, when evaluating the spreading of knowledge about local/traditional medicines also talked about the financial aspects involved in the exploration of natural resources. Further along this same discussion, teacher F would follow up from student B's idea to ask them about other financial costs involved in the production of conventional medicines. Student A, for instance, talked about quality control and testing as costly steps that need to be taken in order check the effectiveness of these products, something that she had already previously alluded to in the extract above.

Similarly, while teaching about Magnetism, teacher F not only employed a more diverse set of examples than in his regular lessons on this topic, but carried out more in-depth discussions about them, even when talking about everyday life items, such as in the case of homework about magnetic materials at home (task 2 – lesson 2). Students were asked not only to present their research about magnetic objects they had found in their homes, but also to think and share their ideas about the following questions: "Do you think people need to know how magnetism works in order to use these appliances at home?"; "Did people know how to explain magnetism in the past when they were using it to find their location or collect metals?"; "What do you think is the difference between science and technology?".

This type of in-depth approach to the examples very often led to reflections about NOS aspects. During lesson 2 of the Magnetism TLP, for instance, students worked in pairs on a task about the compass and Great Navigations (already mentioned in the previous section and seen in figure 19) and were asked to think about different impact of being able to travel around the world on different areas such as the economy, science and technology, politics and everyday life. Ideas produced by this peer work involved, for example: "this could benefit politics because they want to develop trades with other countries"; "people would be getting more materials and trading them"; "more profit"; "they would meet other scientists, therefore sharing their ideas"; "make more profit if a company was set all over the world"; "they [politicians] can travel and make deals":

> Teacher F: "Have you got one for science and technology?" [points to student D, who had previously volunteered by raising his hand].
> Student D: "Yes! **So I said that, for instance, we talked about medicines, 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 brains, or more people, you can have more knowledge going into medicine..."

Teacher F: "Brilliant! [...] Now politics, it's probably the hardest one here..." [points to another student who volunteered].

Student E: "**You can have politicians talking things through, to decide things**."

Teacher F: "Yes, making deals with other politicians and things like that."

Student F: "**A country can use its power on other countries, like the British Empire.**"

The in-depth exploration of Darwin's and Wallace's works also promoted discussions about NOS during the Evolution TLP. After showing two videos[98] about their lives and works to his students, teacher F stimulated reflections about the development of new explanations and theories in science with the help of some follow-up questions[99]. This thorough work around Darwin and Wallace generated not only reflections on epistemic aspects of NOS, but also on social and institutional perspectives behind scientific development: students talked about theories as explanations that are specifically backed up by different sets of evidence, highlighting the importance of collecting evidence to the development of a theory and connecting that with Darwin's and Wallace's travels around the world ("the variety of evidence can give strength to a theory"). They also mentioned ideas related to reproducibility ("important to have evidence from different places to check if that happens everywhere") and collaborations ("working as a team") as important aspects when working on new scientific ideas and theories.

One student connected this historical case to another instance he had previously heard about – the dispute between Thomas Edison and Nikola Tesla during their work in the field of electricity in the nineteenth century – and asked teacher F if they could be considered similar cases. The teacher then used this student's contribution to compare both stories, highlighting the complexities of the scientific community, and ideas such as hierarchy and peer review.

Looking at these different in-lesson events, we can notice how the use of examples through more in-depth approaches promoted an almost natural pathway for

[98] About Darwin: https://www.youtube.com/watch?v=WAKppAtIeh8

About Wallace: https://www.youtube.com/watch?v=uo-BxHWtGNQ&t=301s

[99] 1. Can you explain the relationship between Natural Selection and the Theory of Evolution of species?; 2. Why do we call the explanation for the Evolution of species a 'theory'? What do scientists mean by the word 'theory'?; 3. What is the difference between an explanation and a scientific theory? (think about the ideas about evolution in your cards); 4. How did Darwin and Wallace develop their theories about natural selection and evolution? Based on what?; 5. What is the importance of Darwin and Wallace's travels to the development of the theory of evolution?; 6. Can you think about different reasons why the British government was interested in these travels of natural surveyors around the world?; 7. Darwin and Wallace did not originally work together on their theories, but they eventually exchanged several letters and comments on each other's works.; 8. Why is this important to science? How did that help them?

discussions about NOS in these TLPs. Talking about science and its nature in the case of these TLPs then seemed to be an intrinsic part of the lessons, an expected outcome since the introduction of NOS was an explicit goal of this study from the beginning. What can be inferred from this experience then is that when planned and actively integrated into the TLP with the help of an in-depth work with the chosen examples, NOS aspects can be explored by the teacher explicitly without losing sight of the scientific content expected for that lesson. This was especially relevant in the case of the Magnetism and Earth's resources TLPs, topics that are not traditionally connected with NOS aspects in most schemes of work linked to the national science curriculum in England[100].

It is also worth noticing that some questions, for instance, about Darwin's and Wallace's works (e.g. question 6), also promoted discussions about NOS elements that are not traditionally found in resources available for teachers, such as: political and financial background for the funding of naturalist travels ("influence other countries and show them our scientific development", "increase Britain's popularity", "to make profit", "to get access to natural resources", etc). As argued in chapter 2, some elements of NOS, especially those of epistemic nature (e.g. theories; models; experimentation; methods), tend to be more commonly found in NOS teaching proposals. Other aspects – mainly of non-epistemic (social-institutional) nature such as collaboration, negotiation and adaptation of scientific knowledge, exploitation of natural resources and knowledge, ethical, economic and political aspects of science –, however, are less seen in this type of materials.

In the context of this study, the examples and discussions carried out by teacher F highlight the possibilities offered by the intercultural model of HOS to the work with these less common aspects of NOS, which are as relevant to intercultural narratives as more commonly explored NOS elements. The effects of this type of approach were also seen in the teaching about Earth's resources. Their work on an interactive map[101] containing the distribution of metals around the world ("Where in the world?") comprised the exploration of information about some metals found on this map, followed by a whole-class reflection on two main questions: "If all metals cannot be found in all places around the world, how do you think people learned about their existence in these different places?" and "What do you think they did when they found out about the existence of these different types of metals in other places?". Working on these questions resulted in a whole-class discussion that explored a more global

[100] It is worth remembering here that not only teacher F was observed teaching the Magnetism topic, but also teacher A at school B, and their lessons were indeed very similar in terms of the use of examples and discussions about NOS.

[101] http://www2.open.ac.uk/openlearn/periodictablephase2/elements-world.html

perspective about scientific development, once again including some NOS elements that are not usually found in regular school science resources:

> Teacher F: “How do you think people, if you couldn’t find all these metals on your doorstep, **how do you think they found out about their existence in difference places?**”
> Student G: “**Through trading?**”
> Teacher F: “Trading, yes. What big trading happened that you guys have heard about here before?”
> Student H: “**Ah yeah, with Medicines, there was the Silk Route**.”
> Student I: “**Yes, with the compass as well.**”
> Teacher F: “What else can happen to spread the knowledge?”
> Student J: “**You can navigate around the world and visit different parts.**”
> Teacher F: “Great! That’s how the Spanish got into South America. **And what metal can be found in abundance in South America here in the map?**”
> Student K: “Silver.”
> Teacher F: “Why do you think it took people a while to find these materials? I mean, how come even today there are still some metals that we’ve only recently started to use them properly?”
> Student J: “Because we didn’t know where they were?”
> Teacher F: “Good. That’s a complication. **But even if you knew where it was, what else is in your way, what other barriers are there?**”
> Student L: “**Some natural barriers?**”
> Student M: “**Other people who live in the places.”**
> Teacher F: “How do we call these people?”
> Student G: “The locals.”
> Teacher F: “And what is their part here?”
> Student H: “**They might know more about the metal and you can use them to help getting the metal from nature.**”
> Teacher F: “Right, and what kind of thing they might know that can be helpful?”
> Student I: “**Where to find it and how to get it from nature.”**
> Teacher F: “Great! **We call that ‘extraction’**”.

In this scenario of an in-depth and intercultural approach to the examples, using follow-up questions and stimulating students to share their thoughts on these questions seem to have positively impacted the incorporation of NOS aspects into these lessons. As recently argued by Adibelli-Sahin and Deniz (2017), Hodson and Wong (2017), and Lee and Kwok (2017), explicit discussions can avoid the common oversimplification of NOS elements by overloaded schemes of work while also stimulating students to re-think their ideas when confronted with different views on the proposed questions.

During his experience with the TLPs, teacher F's work with these questions then allowed students to not only express their initial ideas about NOS, but also to reflect about them through whole-class discussions, as seen, for instance, in the extract from the Earth's resources lesson above. In chapter 7, this experience will be further explored, focusing on students' perspectives about and interactions with this type of approach (the remaining theme generated by my observations during the Exploratory phase – 'Interacting with students' knowledge and interests').

Although recognising the importance of planning the development of in-depth discussions about examples and NOS elements in science lessons, we cannot assume, however, that having prepared questions about scientific content and its nature in the TLPs would be enough for promoting explicit discussions about NOS. The place of teacher F in this scenario should also be acknowledged, since, as seen in different research (e.g. Clarke & Hollingsworth, 2002; Höttecke & Silva, 2011; Ryder & Banner, 2013), pedagogical innovations such as an explicit and question-based work with NOS are not only linked to structural aspects (e.g. curriculum reforms or school's leadership), but also to teacher's goals and views about the proposal.

While teacher F had shown interest in this type of innovative approach by having accepted to work with me, he was also asked throughout this experience to constantly rethink and shift his normal practice into a more in-depth approach based on assessment for learning practices. This is not to say that teacher F had to completely change his way of working to be able to implement these TLPs since, as previously discussed, he was usually seen adopting more dialogical strategies in his lessons during the Exploratory phase. The pedagogical shift here was in fact related to how these conversations were employed to promote in-depth discussions about examples and NOS aspects through framing issues around these examples and scaffolding students' initial ideas about them, instead of simply checking their answers as right or wrong or gathering examples.

While we can say that teacher F embraced this new experience with great interest and expectations, not all activities and follow-up questions originally planned in the TLPs were explored by him through this in-depth approach or explored at all. That means he also adapted the TLPs during his lessons, carrying out important transformations of the original lesson plans.

Teacher's use of the TLPs

Throughout this experience, teacher F did not change the original TLPs greatly, but mainly adapted them to what was happening during each lesson – an 'improvisation' type of change (Brown & Edelson, 2003). The majority of these transformations consisted of dedicating more or less time to specific tasks and discussions than originally planned, and referring to more examples to enrich the lessons and also to address students' questions and contributions. The transformations in the original TLPs carried out by him then occurred essentially during the lessons and not beforehand: since we had been working together to develop these TLPs, most of the pre-teaching transformations [an 'adaptation' type of change (Brown & Edelson, 2003)] had already been suggested by him and introduced in the final version of the TLPs.

Interestingly, teacher F seemed very aware of the in-lesson transformations he had been carrying out over the course of his teaching. During our informal chats at the end of each lesson of a TLP, when asked about his impressions of the experience, teacher F would often highlight things he thought to have worked well, and what he had changed in relation to the original plan for the day. This high level of awareness can be connected with teacher F's understanding not only of the TLPs, but also of the goals and expectations related to each planned task and follow-up discussion, a relevant outcome of our collaborative work during the pre-teaching stage.

Among these 'in-teaching' changes there was the management of tasks and discussions. That was the case, for instance, of task 1 in the Medicines TLP, where students were expected to compare herbal and conventional medicines and decide which one they would use if they had a choice, giving their reasons for it (see figure 22 below). During lesson 1, teacher F applied this task at the end of lesson (as it was originally planned), but he did not work on the follow-up questions[102] with his students; hence, no active discussion was carried out about some NOS aspects planned for this lesson, such as evidence, scientific claims and certification of scientific knowledge.

[102] 1. How do we know if the remedies are effective? Is there enough information on the sheets to make informed decisions? What else would you need?; 2. How do you think scientists go about collecting evidence to evaluate these remedies?; 3. Is having evidence enough to convince other scientists and people in general about a scientific idea? What else do they need?; 4. How do you think scientists work with these natural resources? How do you think they go about transforming them into artificial medicines?

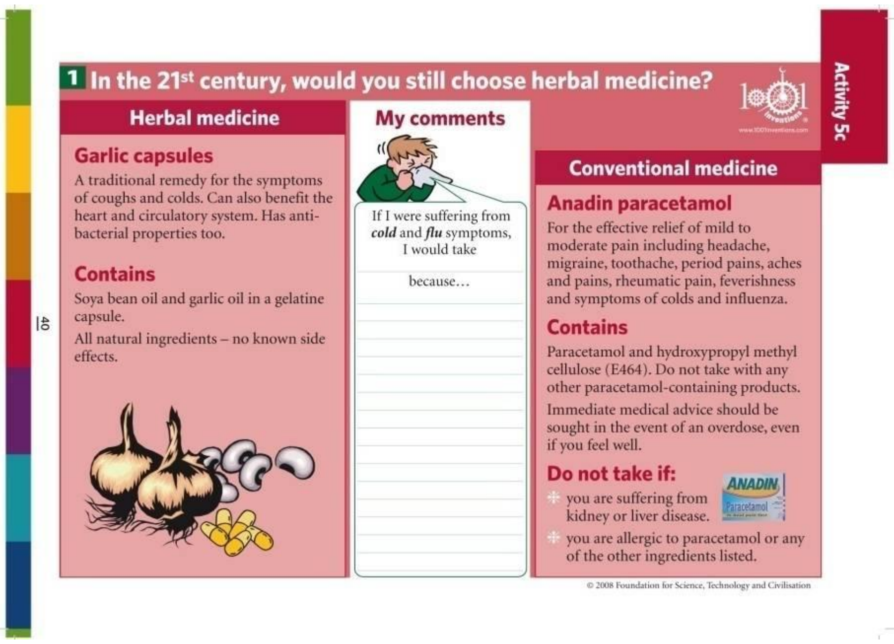


Figure 22. Hand-out for task 1 (Medicines TLP)[103]

The main reason for not carrying out some of the planned discussions can be linked to another theme generated during the Exploratory phase to make sense of my observations: ‘Interacting with students' knowledge and interests’. While these interactions will be further explored in chapter 7, a relevant result from this experience was linked to students’ engagement with the lessons and how it affected teacher F’s ability to manage the time throughout his teaching. During these lessons, students were so interested in the proposed tasks and questions that most of them wanted to contribute to the discussions and to ask extra questions and, in the end, he did not have enough time to cover some of his planned activities, such as the follow-up discussions about task 1.

When asked about this experience after teaching the first lesson on Medicines, teacher F mentioned the lack of time to cover some of its parts more fully, which he attributed to his tendency of being “carried away” by his students’ constant questioning and desire to volunteer as respondents to his questions. Since he was very concerned about students’ engagement with – and interest in – his lessons, his choice was to always try and answer most of the questions, and to give all of them the chance to contribute. This issue with planned time was also seen, for instance, with the Evolution TLP:

[103] Source: http://www.1001inventions.com/

> Researcher: "So, do you have **any comments on this specific lesson plan about the Evolution**?"
>
> Teacher F: "So, **I wasn't expecting it to be like very debate-heavy topic, but there was so much debate to keep going, keep going, keep going that it was a much bigger topic than we planned. [...] It's a much bigger topic than we give credit to be**. [...] And actually what it was interesting was the scope of the content we covered was similar to what we do at A-level; obviously the depth isn't, but the depth isn't far off, and it's interesting to see the kids being able to access it at that depth."

As seen in this extract, teacher F did not expect this topic (and the discussions it promoted) to become 'so huge' when being actively taught. Thus, when planning this TLP, teacher F and I did not foresee its potential to promote several long and engaging discussions with his students, which ended up with tasks and follow-up questions spilling out to the following lessons. In this scenario, it is important to reflect about how the use of a more dialogic and question-answer based approach on the one hand stimulated fruitful and in-depth discussions about examples and NOS aspects and, on the other hand, resulted in a situation where time became an obstacle to the development of all the expected activities. This experience highlights the complexity behind dialogical approaches, and how a balance between different questioning strategies, such as conceptually open and closed questions, can be relevant to the integration between NOS elements and scientific content.

After the second lesson of Medicines TLP, teacher F then decided to try and avoid addressing all their questions all the time, and to select fewer but more diverse volunteers to answer his questions and to contribute with the lessons in general. This diversification of the selection of volunteers was in fact seen throughout the rest of this TLP and in the other TLPs and helped teacher F to engage with different students. Here, his awareness about the limitations and possibilities of different pedagogical practices and how they could be operationalised within the original TLP highlights both an increasing familiarity with the main goals of this experience and the importance of taking into account his professional expertise when planning and implementing these TLPs, as previously argued by Ball and Cohen (1996).

As this experience advanced throughout the Magnetism, Evolution and Earth's resources TLPs, teacher F became more comfortable with time management and flexibility of his lessons, a possible effect of his increasing familiarity with the structure of the TLPs, both at the historical-epistemological and the pedagogical dimensions. During lesson 2 of the Magnetism TLP, for instance, he was supposed to have a conversation with the students about the relationship between science and technology following-up from their homework (task 2 – 'magnetic materials at home'), but he opted to do it very briefly (this lesson was shorter than expected due to technical issues with the computer in the room) and then to move forward to the main topic of the lesson (magnetic forces). In the next lesson, however, when talking about the compass and Earth's magnetic field, he re-introduced this theme on science and technology into the conversation as a recap from lesson 2, connecting it with the use of the compass and having the in-depth discussion expected for the previous lesson at that moment of lesson 3.

Similarly, he continued to adapt his lessons more independently and confidently during the Evolution TLP. For instance, at the end of lesson 1, having no time left to show and discuss the video about Wallace's works with his students, teacher F mentioned at our informal chat that he was planning to start the next lesson with a Q&A to recap Darwin's works and then connect him to Wallace and the video. That indeed happened at the beginning of lesson 2, in which teacher F linked Darwin with other scientists who had been also working on ideas about natural selection and evolution at the time, thus introducing the students to Wallace's works.

This approach was also seen in the case of the Earth's resources TLP, in which teacher F's ability to manage and adapt his lessons ended up in a final TLP that was taught in more lessons than originally planned (six instead of four), but still covering all the content and NOS aspects expected, while also leaving time for students' participation and questions. For instance, he did not have time to cover the idea of 'how metals are found in the world' due to some technical issues at the end of lesson 1, which prompted him to tell me about his plan to start lesson 2 with this idea and then connect it with extraction methods, the original topic for this second lesson.

On a similar note, teacher F also seemed comfortable when responding to students' own questions and bringing more examples and extra follow-up questions to the lessons. Once again, while advancing through this experience, he started to constantly add more to the original proposal, with examples of this active work seen not only in the Medicines[104] and Evolution[105] TLPs – which he was supposedly more

[104] E.g. discussing modern production of aspirin after a student's question; talking about high street shop and herbal medicines in task 1; using IVF to exemplify 'in-vitro' tests.

[105] E.g. talking about the Natural History Museum in London as an example of place involved in the systematic collection of samples related to natural selection and evolutionary ideas; introducing and discussing modern white supremacists - such as KKK members and some *youtubers* - and their discourses about race.

comfortable with due to his background in Biology – but also in the Magnetism[106] and Earth's resources[107] TLPs.

Another relevant point of teacher F's work with the TLPs was related to the discussions about NOS. His work with the follow-up questions about NOS aspects evolved throughout this experience, with him becoming more able to establish his own connections between NOS and the specific examples and tasks as the lessons advanced, also including extra talks about NOS when compared to the original TLPs. That was the case, for instance, of his discussion on science and technology during the Magnetism TLP mentioned above. Similarly, he talked about 'north' and 'south' poles during lesson 3 as arbitrary choices made by scientists to facilitate the understanding of the phenomenon behind Earth's magnetic poles, and about the randomness of predictions about natural phenomena when answering students' questions about the Northern Lights during lesson 4.

In the case of the Evolution TLP, this extra work on NOS aspects was seen, for instance, when one student compared the relationship between Darwin's and Wallace's works with the Tesla and Edison feud, and, as already mentioned here, teacher F decided to use these two historical cases to discuss the complexities behind the work within the scientific community. During lesson 4, teacher F also deepened the planned discussions by challenging students to think about the meaning of 'making rational decisions' when talking about race and eugenics and about the relationship between science and social decisions. Here he stimulated them to think about what being 'rational' stands for and its relationship with what scientific work often entails, talking about the impact and limitations of scientific evidence and explanations to social decisions.

In summary, after being involved in the development and teaching of this sequence of TLPs, teacher F seems to have increasingly taken more ownership of these materials, especially in relation to discussions about NOS, use of follow-up questions and time spent on tasks, examples and discussions. According to Edelson (2002) and Roblin and colleagues (2018), innovative teaching resources organised in a long-term and interconnected approach (instead of as stand-alone materials) offer more interesting possibilities not only for students' learning (to be explored in chapter 7), but also for teachers' learning and perceived self-efficacy in relation to their practices. Teacher F's work with these TLPs throughout this experience then illustrates

[106] E.g. discussing magnetism and haemoglobin; clarifying the differences between the compass and GPS systems after students' questions on the topic; asking students about 'feeling' the Earth's poles moving.

[107] E.g. talking about Welsh gold as an example of his experience with 'local' metals; mentioning a space jacket made of recycled plastic; talking about engineering works carried out in London rivers on sewage management.

the importance of a collaborative approach to the development and enactment of innovative practices, while also highlighting the positive effects of a long-term and coherent perspective about curricular innovation that goes beyond one or two specific resources.

In the next subsection, further insights into teacher F's overall impressions about this year-long experience will be explored, focusing especially on our conversations throughout this phase.

6.2.2. Teacher's impressions about the experience

Teacher F's impressions about our work on the TLPs were investigated through quick chats carried out at the end of each lesson, through a follow-up interview immediately after the end of the teaching of each TLP, and through a final interview at the end of the school year. He seemed generally satisfied with the results during this experience, especially with students' engagement and questioning, also noticing how even students considered by the school as low achievers[108] were also participating and interested in the lessons.

At the end of the Medicines TLP, when asked if he was still feeling comfortable with our work together after actively teaching this material, teacher F stated that he had not seen any big issues apart from the already mentioned concern with time management. He also mentioned that my presence in the room was important to him, especially due to the possibility of being supported in cases when he did not know the answer for students' questions. It is important to remark here, however, that he did not need my theoretical assistance[109] in any of the observed lessons for all TLPs. This scenario once again highlights his growing familiarity with the main ideas behind this experience, which can be linked to our close work at the pre-teaching stage.

This positive overall assessment seems to have continued in the Magnetism, Evolution and Earth's resources TLPs and, when asked again about the experience, teacher F confirmed that he was still very satisfied:

> Teacher F: "I think with this one [Magnetism topic] we're going to see with their work that they'll produce next week, their assessed work, **I'm heavily confident that the majority of them will do well in the magnetism section**. That's based just on my feeling of the classroom you know, **who is giving responses and their work**."

[108] Despite the group being of mixed abilities, the teacher had informed me prior to the start of my work who was expected to be on top and bottom sets when progressing to the KS4 curriculum.

[109] I assisted him only in organising the classroom, distributing hand-outs to students, and collecting their works.

Researcher: "So, do you have **any comments on this specific lesson plan** [Evolution]?"

Teacher F: "So, **I wasn't expecting it to be like very debate-heavy topic, but there was so much debate to keep going, keep going, keep going that it was a much bigger topic than we planned. [...] It's a much bigger topic than we give credit to be**. [...] And actually what it was interesting was the scope of the content we covered was similar to what we do at A-level; obviously the depth isn't, but the depth isn't far off, and it's interesting to see the kids being able to access it at that depth."

Teacher F: "So what I felt with this one [Earth's resources TLP] was that **there was more content that kids could access**. If you imagine like a pyramid, I feel like the base of this topic is wider, so **I feel like quite often we were going further and further into new knowledge and I knew they were being able to follow and access it.**"

Researcher: "Ok."

Teacher F: "So with this topic **I feel students were able to access so much of it, to a new and deeper level of knowledge. So they were even more prone to ask questions going further and further into it.**"

When talking about what had worked well during this work, teacher F mentioned the constant use of follow-up questions, the organisation/structure of the lessons, and the resources available as the most positive aspects. After the Magnetism TLP, for instance, he connected the questioning approach with students' engagement and with their confidence in the discussions being proposed:

Researcher: "Was there anything that you thought 'maybe this is not working'?"

Teacher F: "No [...]. **There were parts in the lessons where I was thinking like 'oh, this isn't going to work', and then I realised it was working.** So the repetition that I was telling you about, where you know, just from the nature of the slides I suppose, **you have an idea for classroom discussion, and you're guiding the discussion, you summarise it, and then the next slide basically gives you these questions about what you've been talking in the past 20 minutes**. And I as a teacher before would quite often ignore that part, and we would skip that bit because 'oh, we just talked about that'. **Whereas, being there and doing these interactions and looking at the students faces and not seeing boredom, this was nice**. [...] In reflection, **I think there were parts of the lesson as I was approaching them I was thinking 'oh this is going to be tricky', or 'I'm gonna lose them now', and then I didn't, so... good**."

Researcher: "So **you think they're engaging well with the lessons?**"

Teacher F: "Yes. To go back to these questions, **I'm surprised at how engaged they remained even when to me it feels like 'they already summarised this' when I ask them again. But they are than happy to answer it again. Clearly they are gaining some sort of confidence from that I'd say**."

As seen in the extract above, teacher F also highlighted the importance of the 'spiral' approach to the introduction of NOS elements. As argued in section 6.1, this decision to explore the same NOS aspects in different parts of lessons and in different TLPs aimed at aiding students to establish connections between diverse topics, and to create a 'big picture' of scientific work throughout this experience. While effects of this decision will be further analysed in chapter 7, teacher F's impressions about it highlight how this pedagogical choice had positive effects not only on students' learning about NOS (the expected outcome), but also on their engagement with the lessons and on teacher F's learning about his practice.

After the Magnetism and Earth's resources TLPs, teacher F also commented on how the narratives behind the TLPs (that is, the intercultural model) helped him with teaching these topics as a Biology teacher. According to him, this was due to the fact that Magnetism and Earth's resources were presented and discussed as nature-related topics (that is, as part of the natural world) with local and global implications, and with explicit contexts and examples informing each part (tasks and questions) of the lessons. In other words, the topics were explored in a tradition that he sees as more closely connected to teaching Biology than Physics or Chemistry, thus making him more comfortable with these TLPs.

Teacher F's views on the connection between his efficacy in teaching these topics and the global narratives that informed the TLPs then illustrates possibilities from the intercultural model that go beyond students' learning about NOS (my original expected outcome). The adoption of this model for the construction of the TLPs seems to also have impacted teacher F's perceived self-efficacy when teaching outside his subject specialism, offering him new resources and historical-epistemological knowledge to elaborate on his lessons:

> Teacher F: "It's kind of a **different take on the content**, in that it's **teaching about scientists at work**, rather than, like in the past, the bigger picture I would give them would be more about how this content fits in the universe. **But these lessons are also about the discovery of that universe, with this extra bigger picture behind the content**. When I walked away from these lessons and talked to people about what we've been doing, that was the focus of what I said. Like **'I'm teaching through story-telling'**."

During our meeting after the Evolution TLP teacher F also talked about his positive impressions on being stimulated to teach about NOS. He remarked that despite having heard about the importance of NOS to science teaching during his initial teacher training seven years prior, he had never really realised how much this approach could add to a science lesson. He talked about its impact not only on content teaching and on making connections between different ideas and concepts in different lessons (giving a narrative, a structure to the teaching of a whole topic), but also on students' participation:

> Teacher F: "When I started teaching seven years ago **'how science works' was such a forced thing upon us, and doing it in these sequences of lessons, all the way through, it has made me realise 'how science works' was lacking.** [...] **As a trainee I was just like wanting to crack up how to deliver content and manage behaviour, and that was it.** [...] So since then I've ignored 'how science works' for five years, and during these sequences of lessons where the focus isn't really the 'how science works' that I learned, this is actually 'how scientists work'. [...] **But now I'm glad that I decided to do it, because now I can see that you can trust this process [teaching NOS], and I will do with other classes now."**

Following from this comment, I remarked that I had seen him introducing some ideas about NOS into his lessons during my Exploratory phase, but he observed that this had been done by him without any planning and most of the times implicitly. He highlighted that being able to plan this introduction of NOS into his teaching and doing that through the use of questioning had showed him the value of having these ideas embedded in his lessons and not only as extra activities to fill in the gaps of a specific content. Teacher F's impressions of teaching about NOS after engaging with our collaborative experience shows the importance of this type of work when proposing innovative practices and resources, as also found by other investigations in the field (e.g. Höttecke & Silva; 2011; Henke & Höttecke, 2015).

In our final interview, teacher F also talked about the relevance of the resources to his experience with the TLPs (as seen in the extracts below), especially in relation to the materials available for students (e.g. tasks, slides). The fact that the resources were consistent among the different TLPs (the 'spiral' approach) and well-planned impacted, according to him, not only students' engagement with the lessons (helping them to gain confidence throughout the lessons, as previously mentioned), but also his own learning from these materials.

> Teacher F: "**In the end I felt absolutely fine, not out of my comfort zone at all**. And I felt that these resources and working on them provided me with a platform that benefited me a lot as a teacher."
>
> Researcher: "And what did you learn from this experience?"
>
> Teacher F: "Loads of new content. I learned that **students can interact differently with that content, through the questioning**, and that **I don't need to rely so much on hammering the principles on them**. The students actually **can learn through the stories and discussions.** I also learned that students are interested in scientists and

their work. I read a lot about science around the world, but **I didn't know how that could come to this curriculum, which is completely Western-based**. And I also learned that **students don't get frustrated with being asked similar questions in different moments.**"

Teacher F: "**Students know when a lesson is well-prepared and well-resourced**. **Even little things, like the format of the slides, were consistent**. And also, the tasks and having the prepared questions."

Teacher F: "**The activities were great and the resources were great**. What I particularly liked about the resources actually is that they are very easy on the eye, very visual, **with just enough prompts for the teacher to jog around them. Like, there were always questions to prompt the students.**"

Regarding what had not worked, teacher F mentioned the time management issues he had at the beginning of this experience, and how it would be better to have more time to go through the follow-up questions and tasks. More reflections on this specific aspect around the teaching of the TLPs – i.e. interactions between teacher F and his students – will be then further explored in the next chapter.

6.3. Final thoughts on developing and teaching the TLPs

Throughout this chapter my aim was to explore the development and teaching of TLPs based on an intercultural model of HOS and intended to foster the explicit inclusion of aspects of NOS and cultural diversity into regular science lessons, as summarised by RQ4.1: "How can the planning and teaching of these TLPs be carried out to promote the integration of NOS into school science?". Among the findings from this experience, some were closely investigated here, focusing on the development and teaching dimensions:

- The affordances and hindrances of the scholarship in the field of HOS to the use of an intercultural model in the development of TLPs;
- The possibilities offered by the intercultural model of HOS to the integration of epistemic and social-institutional aspects of NOS into the teaching of scientific content;
- The effects of a question-based approach on the explicit teaching about NOS and of a 'spiral' approach on the planning and teaching of the TLPs;
- The importance of a collaborative work with the participant teacher to the development of these TLPs;

• The impact of this collaborative work and of these resources on the teacher's learning and perceived self-efficacy about his practice.

In relation to the field of HOS and its possibilities to the creation of intercultural narratives, it is important to highlight the impact of 'Global History' approaches on bringing to light scientific and technological developments from different communities around the world. This became clear throughout this investigation when comparing the construction of these narratives for the Magnetism and Earth's resources TLPs with the Medicines and Evolution TLPs. While the work on the former was made easier by the tendency in the field to adopt a 'Global History' perspective to these topics, bringing an intercultural narrative together for the Medicines and Evolution TLPs was not as straightforward due to an often locally-based approach.

This is not to say that materials exploring knowledge production about medicines and evolutionary ideas in different places and periods were not available, but that the exchanges, collaborations and transmissions of these different types of knowledge are less explored by scholarship in the field of HOS. Thus, one finding from this study was the complexity behind transforming different types and levels of recent HOS scholarship into educational resources. This challenge, of historical nature, then involved the analysis of these primary sources from an intercultural perspective to assess their possibilities to inform the TLPs.

Still about these intercultural narratives, this specific approach seemed to have offered a pathway for the inclusion of different NOS elements, of both epistemic and social-institutional nature, into the teaching of scientific content. Here, the socio-historical nature of this intercultural perspective (including its focus on exchanges, collaborations and local-global relationships) created a space for social-institutional aspects of NOS to be explored throughout these lessons in a more balanced manner when compared to epistemic ones, as seen in most whole-class discussions carried out by teacher F.

As argued by recent studies in the field (e.g. Aragón-Méndez, Acevedo-Díaz & García-Carmona, 2018; Ideland, 2018), most resources currently available for NOS teaching focus on more philosophically-informed views of NOS, with less attention paid to its social-institutional aspects. Findings from this study then showed the possibilities brought to the field by an intercultural approach to HOS, promoting a more balanced and interconnected work between these two 'dimensions' of NOS. Even more worthy of notice throughout this experience, the distinction between epistemic and social-institutional aspects became blurred, since the narratives constructed to explore different scientific developments were grounded from the start on a perspective that understands these two dimensions as intertwined in the process of knowledge production, as also defended, for instance, by Ideland (2018).

In addition, these intercultural narratives seem to have promoted an integration between NOS elements and scientific content that looked more natural to teacher F, as mentioned during our final interview:

> Teacher F: "I learned that **students can interact differently with that content, through the questioning**, and that **I don't need to rely so much on hammering the principles on them**. The students actually **can learn through the stories and discussions."**

The use of these 'stories', that is, of a 'storyline' informing the development and connecting each lesson in a TLP can be a strategy to bring together the products (scientific content) and the processes of science (NOS). The option of developing a whole TLP around a specific intercultural narrative (e.g. the history of the relationship between science and technology, material sciences, maritime travels, mining and Earth's magnetic field in the case of the Magnetism TLP) then seems to have favoured connections between NOS and content, while also placing teacher F and his students in a situation of growing familiarity with the ideas being explored during the lessons.

Another important result from this study was the impact of the 'spiral' approach on the links between NOS ideas not only among different lessons from the same TLP, but also among different TLPs. As mentioned by teacher F during our final interview, the fact that similar questions about NOS were being proposed to students in different moments of the school year allowed even the often less engaged students to feel they could contribute to the lessons. This was related, according to him, to their gain in confidence as the NOS-related questions started to re-appear in different contexts, giving them the chance to keep building their knowledge:

> Teacher F: "Having **worthwhile repetition of similar questions and ideas between the lessons and topics**, which were further embedding students' own ideas, **that would have had a huge impact on them, because even the weaker students would have got a sense of achievement**, because they were able to answer the questions at the end, because of this repetition. […] And here comes the confidence."

Interestingly, this 'spiral' approach seems to be underexplored by most investigations about NOS teaching and learning, which usually focus on teaching different NOS elements in each lesson, but without re-introducing them in different contexts and topics as the experience moves forward (Besson, 2014). Different research in the field of curricular innovation and materials (Grossman & Thompson, 2008; Forato et al., 2012; Roblin et al., 2018) discuss the importance of these long-term and coherent experiences for the introduction of new proposals into school practices, and results from this investigation add to these arguments both in relation to only students' learning (to be further explored in chapter 7) and to teachers' ownership of these new ideas and practices.

As also mentioned by teacher F in the extract above, the adoption of a question-based approach was another relevant aspect of this experience. As argued by Schwartz and Crawford (2004), Clough (2006; 2008), and Lee and Kwok (2017), employing planned follow-up questions can help the teacher to make NOS aspects explicit, while also stimulating students to share their own ideas about scientific work in a space intended to constantly connect these views with different contexts and cases. In the next chapter, more attention will be paid to students' reception of this approach, but teacher F's comment above about their engagement highlights the positive impact of using planned follow-up questions that are also interconnected among the TLPs.

The last aspect to be explored here is my collaborative work with teacher F. As previously argued, my initial purpose in collaborating with him to create these TLPs was to avoid the common issues with innovative practices made in a 'top-down' style found by other investigations in the field of NOS teaching (Monk & Osborne, 1997; Gooday et al., 2008; Bächtold & Guedj, 2014; Besson, 2014; Chamizo & Garritz, 2014). It was then my aim to get teacher F's professional input for the development of these TLPs to keep a certain level of congruence between the proposals and his regular practice (Janssen et al., 2013).

Nevertheless, this collaborative work seems to have gone beyond getting his professional input by also promoting important moments for teacher F's learning, not only in relation to historical-epistemological content, but also to pedagogical practices such as the aforementioned use of planned follow-up questions, the 'spiral' approach and the integration of NOS elements into his lessons. This close collaboration throughout different stages of this Implementation phase, coupled with the production of resources that did not only include slides and hand-outs but also historical-epistemological and pedagogical ideas, also allowed him to re-think his regular lessons, and especially to change his approach and perceived self-efficacy towards topics outside his subject specialism.

In this case, more than simply using teacher F's reality to inform the development of these TLPs, this experience resulted in him taking ownership of these resources to the extent in which he started to actively share them with other teachers at school A. This result then illustrates the importance of partnerships between teachers and researchers on classroom innovations not only to students' learning, but also to teachers' professional development and perceived self-efficacy.

Chapter 7: Implementation phase – Learning through the intercultural model of HOS

In the previous chapter, the Implementation phase was analysed through the lenses of the 'development' and 'teaching' dimensions, focusing on our work around the TLPs. In this chapter, a final dimension of analysis about this experience will be considered – 'students' –, exploring the impact of the TLPs built with the intercultural model of HOS on students, both at the experience and learning levels, aiming to answer RQ4.2: "In which ways can this approach impact students' understandings of NOS and what are their views about this experience?"

The first level explored here delves into students' impressions about the TLPs and their interaction with the lessons, discussions and tasks proposed by teacher F (inspired by my analysis of lessons observations carried out during the Exploratory phase). Meanwhile, the learning level addresses specifically NOS and content, investigating whether the TLPs reflected on how students talked about NOS elements and on their exam results at the end of the school year.

7.1. Students' experience of the TLPs

Students' work with the TLPs was investigated during the teaching of these materials (informed by field notes from my observations), through extra questions added to the post-Implementation HOS questionnaire (see appendix 12) and in a final focus group at the end of the Implementation phase (see appendix 13). This level looks into students' main impressions about the TLPs and about their work with teacher F. In this last case, I was specifically interested in interactions initiated by the teacher (asking specific questions about concepts, NOS, opinions and for examples), by the students (asking specific questions about concepts, NOS, and examples), and in peer interactions (peer discussion about examples and tasks), as summarised by the theme 'Interacting with students' knowledge and interests' generated during my Exploratory phase to make sense of my lesson observations.

As an overall result, students seemed engaged with the lessons, with many asking questions (students' initiation), working on the tasks proposed, and volunteering to answer questions proposed by teacher F (teacher's initiation). It was especially interesting to see how students considered as being low achievers by school A were particularly engaged with the follow-up questions about NOS when compared with how they had been seen in previous lessons[110]. One example here is student A, considered to be a low achiever by school A, who participated in a discussion on how the knowledge about the compass arrived in Europe (part of the slides in figure 19), as seen below. Even after having missed the previous lesson of the Magnetism TLP, this student was able to connect the main idea teacher F was exploring at that moment with discussions carried out during the Medicines TLP, illustrating the relevance of the 'spiral' approach to students' engagement and confidence throughout these lessons, as previously addressed in chapter 6.

> Teacher F: "Can anyone remember **how this technology [the Chinese 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?'**"
> Teacher F: "Good. So you [student A] 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? Can you remember?**"
> Student A: "Oh, **the Silk Route**!"

Nevertheless, as highlighted by teacher F in the previous chapter, the need to rush through some tasks and questions occasionally resulted in less time available to further develop these activities and to stimulate and explore more thoroughly students' own questions and interests, with most lessons being more centred on teacher's initiations than on students' initiations. Here, the choice of having planned questions to guarantee discussions about NOS and content under the available timescale might have constrained possibilities for other types of interactions in these lessons, favouring teacher's initiations over students' initiations.

While some recent studies in this field try to promote student-centred NOS learning through inquiry-based approaches (e.g. Khishfe & Lederman, 2006; Kyza & Levinson, 2014; Bencze et al., 2015; Bencze, 2017), the majority of proposals adopting a historical perspective tend to be based on questions and discussions initiated by teachers (e.g. Clough, 2006; 2008; Höttecke & Silva, 2011; Forato et al., 2012; Guerra et al., 2013; Aragón-Méndez, Acevedo-Díaz & García-Carmona, 2018). And although the importance of the teacher as a facilitator in discussions about NOS has already been remarked by different researchers (Matthews, 1994; Papadouris & Constantinou,

[110] This participant group was informally observed during the first half-term, prior to the start of our work on the TLPs, to get a better understanding of the dynamics of the classroom, teacher's relationship with them, and their interests and engagement with the lessons.

2011), reflections about this teacher-led feature of most HOS proposals are still scarce. Future studies carried out under a socio-cultural perspective might then be interested in investigating possible ways of balancing students' initiations and teacher's initiations when planning the integration of NOS into science lessons HOS.

Despite this unbalanced scenario, it is important to remark that a significant number of students' initiations were seen not only in their questions about examples and ideas, such as natural medicines used by their families, how sundials work, interspecies breeding, or production of bronze, but also when NOS aspects were involved. The extract below contains a discussion during the lesson on vaccines (Medicines TLP) about Onesimus, an African slave who helped community leaders in Boston/USA to fight a smallpox epidemic around 1721:

> Student B: "My question is: **how does an African slave brought to Boston, in America, find something that cures a lot of people only in 2 or 3 years? How is that possible?**"
>
> Teacher F: "What do you mean? Explain a little bit more."
>
> Student B: "How this man, coming as a slave from West Africa, met some random white person that bought him and took him to Boston, and he is like **'sir, I know how to cure this smallpox'?**"
>
> Teacher F: "Yes, that's because **it was his knowledge, because in Africa they had been treating smallpox with inoculation techniques, so they've probably been doing that for years, and years, and years, so he went to America and saw people suffering from this disease it was easy for him** to hold his hand and say 'excuse me?' It doesn't mean that he discovered it, it's just that he had the knowledge, because probably he was taught by his family. Ok?"
>
> Student B: "Oh, so then **that would be passed on to other people?**"
>
> Teacher F: "Yes, so the important thing here is the sharing of knowledge, to look where this knowledge has come from."

This general positive involvement with what teacher F was proposing was the main reason why the amount of time expected for the Medicines TLP to last was surpassed: students' constant questioning and willingness to answer the teacher's follow-up questions resulted in more time needed to finish most of the proposed tasks and discussions. This pattern was seen once again during the Magnetism TLP, but with more time allocated in each lesson plan for these activities, interactions became less rushed. Here, there were opportunities for students' own questions both about concepts and technical aspects of the topic (e.g. examples of magnetic materials and of non-contact forces; the scale of Earth's magnetic field, etc.) and about NOS aspects (e.g. why the Northern Lights cannot be predicted; which type of tests were made by ancient communities with magnetic materials to detect their properties).

During the Evolution and Earth's resources TLPs students were also seen actively participating in the lessons, such as when answering teacher F's questions on conceptual aspects (e.g. previous knowledge about the appearance of life on Earth, natural selection and evolutionary ideas; previous knowledge on the Earth's structure and composition; recap on 'elements', 'compounds', 'mixtures', etc.) and on NOS aspects (e.g. discussing the differences between regular explanations and scientific theories; reflecting on the meaning of 'rational decisions' and its relationship with science and society). Students' initiations were also part of these two TLPs, involving questions both about conceptual aspects and examples employed by teacher F (e.g. the use of cloning as a method to preserve biodiversity; specific characteristics of some endangered species; inter-species breeding; carats system; radioactive elements) and NOS elements (e.g. how the scientific community works and the Tesla and Edison feud; why there are different guidelines for recycling in different boroughs and countries; whether wars can promote access to different natural resources like minerals).

Students were also dedicated to the homework proposed by the TLPs[111]. According to teacher F, students at school A are not used to having science homework, so the fact that at least half of the group (usually around 15 students) worked on those indicates a good degree of engagement with these tasks. The first homework of the Medicines TLP (task 2 in the TLP, and already mentioned in chapter 6), for instance, was positively received by most students, who vocalised they interest in researching natural medicines used by their own communities.

Homework in the Magnetism TLP also promoted students' engagement with the lessons, mainly due to their high interest in sharing their research with the rest of the group and in asking teacher F questions about their work. That was the case, for instance, of student C sharing what she had learnt about her own father's use of magnetic machines in his work as a carpenter (task 2 – "magnets at home"):

> Student C: "In magnetic machines, **my dad said that some machines have certain magnets depending on what material you're using in it. Like, he works with metal and wood, and when the MRI links with the metal, it holds it in place to help him.**"
> Teacher F: "Alright, so he uses a magnetic machine in his work, does he?"
> Student C: "Yes."
> Teacher F: "Interesting, what does your dad do again?"
> Student C: "He's a carpenter."

[111] Medicines TLP: the first about the use of a natural medicines in a specific culture and the second about modern cures and treatments for diseases; Magnetism TLP: the first about magnets at home and the second about magnetic phenomena in nature and outer space; Evolution TLP: on a species' family tree; Earth's resources TLP: on the history of exploitation of a metal and another on the lifecycle of a metal.

Interestingly, some types of activities seemed to have stimulated students' engagement with the lessons more than others. While the follow-up questions and homework appear to have promoted a good level of interest in what was being proposed by teacher F, activities that involved students group work (peer interaction) very often resulted in issues with behaviour and disruption. That was the case, for instance, of task 4 in the Medicines TLP, and its group debate about the Ebola epidemic: students were asked to get into groups and assume the role of a specific person in the debate. Nevertheless, instead of discussing the arguments within their groups, most of them were scattered around the room instead of working on the task.

On the other hand, when presenting them with another task involving a debate two lessons later (task 6 – about compulsory vaccination), teacher F decided to have it as a whole-class discussion, with each student having time to think about their arguments and then volunteering to present them to the whole class. The teacher thus acted as a facilitator of the debate, challenging their arguments/answers and stimulating others to contribute. They seemed to have engaged with this task more productively, without behaviour issues and with relevant contributions and questions being asked. This result can possibly indicate how students might be more used to a teacher-centred environment in their science lessons than to working together on specific tasks, as also remarked by Hand and Levinson (2012). Once again future investigations in the field might choose to explore how proposals on NOS and HOS can be developed to stimulate more students' initiations and student-student interactions while also taking into account teachers' place in these types of approaches.

Based on this experience with debates, teacher F opted to work only with paired groups for the tasks in the next TLPs, which generated fewer behaviour issues during the lessons, while also giving his students the chance to work on some tasks together (student-student interaction) before moving on to his follow-up questions (teacher's initiation), as also done by Leach and others (2003). In the Magnetism TLP, for instance, that was the case of task 3 (about impact of the Great Navigations), already discussed in chapter 6, and the final practical on drawing magnetic field lines using compass and iron filings (task 5), during which almost everyone was able to complete an activity that, according to teacher F, most usually do not manage to finish[112].

For the final TLP (Earth's resources), teacher F decided to use this paired approach also for his follow-up questions: he asked students to discuss their ideas about these questions first in pairs (for around 1 minute), and then to share them with the rest of the class afterwards. According to him, his intention was not only to stimulate short sharing moments between his students, but also to allow those who

[112] This same activity was observed in teacher A's (school B) lesson on Magnetism during my Exploratory phase and her students had indeed great difficult in working on this task.

usually avoided speaking in whole class discussions to contribute more freely, giving more students the opportunity to reflect about these questions. While his overall impression about this experience was positive at the end of this TLP, he highlighted that this approach used up more time from the lesson, slowing it down.

It is worth noting that this strategy of having paired and whole class discussions was one of the aspects students most enjoyed about their experience with the TLPs. Among the 25 respondents to the post-Implementation HOS questionnaire, 13 mentioned they liked the follow-up questions and discussions proposed by teacher F and, during our final focus group, this was illustrated by student D:

> Student D: "**I think in most of the other lessons we don't engage with the teacher, we do more textbook work."**
> Researcher: "Ok."
> Student D: "**I kind of prefer the question-and-answer, because after we say something he can actually explain more things to us that are linked to the question**, whereas with the textbook we just have to, like, understand by ourselves."

In this post-Implementation questionnaire students also mentioned "good learning" (15), "tasks"/"worksheets" (8) and "fun" (7) as aspects they had enjoyed about these lessons. Their positive feeling about this experience was also the first aspect they mentioned when asked a similar question during our final focus group:

> Student D: "The thing I liked the most was that **we've got to find out interesting information that we didn't know about**, that we haven't learned in the past."
> Student E: "I like how **we could find out the history of it, what they did in the past, and how it used now**."
> Researcher: "Ok, and why do you think this is nice?"
> Student F: "I like because **it showed how things changed in science and in technology, how they develop.**"
> Student G: "I find it interesting to **learn about it, about the process**. I also **liked the little sheets** we had."
> Researcher: "And why is that?"
> Student G: "**All these activities, with the new information, were fun**, it's nice to learn about different things."
> Student D: "**One thing that I like about the history is that you can see how the same thing is used in different ways and it has developed**."
> Student H: "It's different to other lessons."
> Researcher: "**What is different from your other science lessons?**"
> Student G: "In normal other lessons **we don't learn about scientists and with these lessons, as you learn about the development, you learn about the scientists, how they work and how things changed.**"

In this group discussion we notice their interest in the activities proposed and in the stories about scientists and scientific development introduced by teacher F, and how this approach was different from their previous experiences with school science, as also observed and discussed in relation to my Exploratory phase. They missed, however, other aspects of science lessons that were not an integral part of these TLPs, such as experiments and writing down on their notebooks.

In relation to practicals, 10 students mentioned in the post-Implementation HOS questionnaire that they would have liked to have more of them, something that was also pointed out by some of them in the final focus group. This is not an unexpected result, since students' interest in and enjoyment while carrying out experiments is well-reported by different research in the field (Osborne & Collins, 2000; Wellington, 2005; Toplis, 2012). Nevertheless, the challenge in this investigation was to balance the work with both HOS and inquiry, while also having enough time to carry out the explicit discussions about NOS that were the main part of these proposals. Time constraints and teacher F's own teaching preferences then informed the decisions made in relation to the amount of practicals that would be included in the TLPs:

> Researcher: "Students mentioned that didn't do many practicals."
> Teacher F: "**I don't do many practicals**. Whereas in last year they had [another teacher], and she's a proponent of having demonstrations at every lesson. And I'm not. **Demos in every lesson, I think there's a place for that, I think it's realistic within the constraints of our curriculum; doing a practical every lesson, that's not** […] And there's research about, isn't it, about how doing practicals does not necessarily ensure learning? […] **And with the timetable, having only single lessons with them, that's really difficult to have a proper discussion about a practical.**"

Students also commented during the focus group that, while the lessons were engaging, fun and offered them a "good learning", they had not written a lot in their notebooks, which meant not having notes to help them to revise for their end-of-the-year exam. This finding points to the impact assessment has on students' perceptions of school science even at the KS3 cycle, and to how some school practices linked to a transmission model of teaching (e.g. copying from the textbook) are still part of their experiences of their science lessons, as also found by Henke and Höttecke (2015).

While these comments are completely legitimate in the context of concerns about their future options for GCSEs studies, it is worth remarking the ambiguity behind believing they had had a "good learning" throughout these lessons, while also being afraid of not having enough notes to revise for their exam. In the end, their results ended up being above the average of all other year 8 groups at school A, as it will be discussed in the next section, hinting to an overall positive impact of these TLPs not only on their engagement and enjoyment of the lessons, but also on their learning.

7.2. Learning from the TLPs: NOS and content

Students' learning from the TLPs was mainly explored during and after the teaching of the TLPs, being informed by: my field notes written during the observation of the lessons; students' own productions (students' tasks and NOS diaries, group mind maps, pre and post-Implementation questionnaires); a final focus group at the end of the school year; and students' results in their end-of-year exam. My focus here was to investigate how the TLPs impacted their understanding about NOS, while also considering effects on their exam marks.

As briefly mentioned in chapter 4, my main goal throughout this phase was to understand the potential of the intercultural model of HOS to the teaching and learning about NOS, aiming at expanding and diversifying a field that traditionally relies on very few paradigmatic examples from the HOS. Therefore, HOS was employed in the TLPs as a pedagogical and curricular strategy, that is, as a vehicle to promote consistent and coherent discussions about NOS among the participants and throughout the school year. That means that learnings about specific episodes or events from the HOS were not considered as the main expected outcomes from this experience, but as natural by-products of a more diverse and in-depth engagement with NOS itself. That being said, throughout this section I will focus on students' learning about NOS – the envisioned outcome from the TLPs – while some comments about impact of this experience on their views about HOS will be addressed with less emphasis later on this chapter.

One of the main sources of information about students' understandings of NOS were their NOS diaries, written at the end of each lesson of the TLP (when possible) and guided by the question "what did you learn today about how science and scientists work?". The following tables 9, 10 and 11 summarise the main trends found in these diaries during the Medicines, Magnetism and Evolution TLPs[113], respectively, and compare them with the aims of each correspondent lesson in terms of NOS elements.

[113] Students' work on these NOS diaries was not carried out systematically during the Earth's resources TLP due to the need of finishing the lessons early at that time of the year so students could attend extra-curricular activities promoted around the school (e.g. Arts festival, careers talks, KS4 interviews, etc.).

Table 9. Expected NOS learning objectives and students' responses to their NOS diaries in each lesson of the Medicines TLP

Lesson	Expected NOS aspects	Trends from students' diaries (outcomes)	Example of quotes about NOS from the diaries
1	• The importance of natural resources for the production of scientific knowledge. • Collaborative and collective nature of the scientific work. • Understand and evaluate scientific claims through evidence and testimony.	• Knowledge about plants and medicines come from different places around the world.	"I learnt more about global and ancient medicine and how medicine has grown due to trading."
		• Collaborative and long-term nature of scientific work and knowledge.	"I learnt that people from different countries shared cures for illness. This helps in science as today scientists can study the cure and create new ones." "Scientists learn from each other to improve their knowledge."
2	• The importance of natural resources for the production of scientific knowledge and the consequences of their exploration (including environmental issues and intellectual property in science). • The relationship between science, ethics, economy, politics, etc.	• Connections between environmental issues and production of medicines.	"I learnt that there are many cures but we do not know what they are due to deforestation."
		• Importance of testing/trials in science.	"They have to do a lot of tests to make sure of the drug."
		• Long-term and high-cost nature of scientific work and knowledge.	"It takes long to process the drugs and it comes from many different places."

Table 9. Expected NOS learning objectives and students' responses to their NOS diaries in each lesson of the Medicines TLP (cont.)

Lesson	Expected NOS aspects	Trends from students' diaries (outcomes)	Example of quotes about NOS from the diaries
3	• The relationship between science, ethics, economy, politics, etc. • Social and cultural influences and controversies in the production of scientific knowledge. • The role of experiment, controlled investigation and quality control in science.	N/A[114]	N/A
4	• Understand and evaluate scientific claims through evidence and testimony. • Collaborative and collective nature of the scientific work. • Social and cultural influences and controversies in the production of scientific knowledge.	• Relevance of evidence to scientific discoveries.	"You have to back up your discovery with evidence to be believed."
		• Collaborative nature of scientific work and knowledge.	"A West African man was slaved and brought to Boston; he found out that they all have smallpox and he knew the cure so he told everyone in Boston."
		• How vaccines work in our body.	-

[114] When students' diaries are not available that means there was not enough time at the end of that lesson for them to work on this instrument.

Table 9. Expected NOS learning objectives and students' responses to their NOS diaries in each lesson of the Medicines TLP (cont.)

Lesson	Expected NOS aspects	Trends from students' diaries (outcomes)	Example of quotes about NOS from the diaries
5[115]	• Understand and evaluate scientific claims through evidence and testimony. • Social and cultural influences and controversies in the production of scientific knowledge. • The relationship between science, ethics, economy, politics, etc.	• The place of evidence and testimony in scientific research.	"In today's lesson I learnt the scientists have to prove their methods of vaccinations and that a scientist fooled people as well."
		• Social and cultural influences and controversies in science.	"I learnt that people have many different views on vaccines." "I learnt that vaccination was a serious case. There were arguments depending of if children should be or not vaccinated."
		• Scientists' ethics and the production of scientific knowledge.	"I learnt why scientists would fake results and why people think vaccines are dangerous."

[115] Lesson 5 was added to the original lesson plan; it was dedicated to the debate about vaccination and discussion about the MMR controversy (there was not enough time in the previous lesson – lesson 4).

Table 10. Expected NOS learning objectives and students' responses to their NOS diaries in each lesson of the Magnetism TLP

Lesson	Expected NOS aspects	Trends from students' diaries (outcomes)	Example of quotes about NOS from the diaries
1	• The importance of observation and indirect evidence in Science. • Science is tentative, creative and does not answer all the questions.	• Which materials are magnetic.	-
		• How magnets work in terms of attraction and repulsion.	-
2	• Social and cultural aspects of science (commercial aims, contextual influences, exchange and transmission of knowledge). • The relationship (and differences) between Science and Technology.	• Long-term and collaborative aspects of scientific development.	"I learnt that it took a long time for scientists to realise how magnets work." "I learnt that scientists go to different countries to share ideas."
		• Different applications of magnetism.	-
		• How magnets work (attraction and repulsion).	-
3	• The role of modelling in science. • The importance of observation and indirect evidence in Science.	• What magnetic fields are and Earth's magnetic field.	-
		• Relationship between science and technology.	"I learnt the difference between technology and science."

Table 10. Expected NOS learning objectives and students' responses to their NOS diaries in each lesson of the Magnetism TLP (cont.)

Lesson	Expected NOS aspects	Trends from students' diaries (outcomes)	Example of quotes about NOS from the diaries
4	• Science is tentative, creative and does not answer all the questions. • The importance of observation and indirect evidence in Science.	N/A[116]	N/A

[116] When students' diaries are not available that means there was not enough time at the end of that lesson for them to work on this instrument.

Table 11. Expected NOS learning objectives and students' responses to their NOS diaries in each lesson of the Evolution TLP

Lesson	Expected NOS aspects	Trends from students' diaries (outcomes)	Example of quotes about NOS from the diaries
1	• The concept and use of evidence in science. • Reflect about scientific and non-scientific explanations.	• Relationship between evidence and scientific explanations.	"Scientists work through evidence and explanation, they are constantly thinking of scientific explanations that will improve their theories."
		• Different scientists and ideas related to Evolution.	"We learnt different theories and explanations to how different species were made, like change due to habitat."
2	• Collaborative and collective nature of the scientific work. • The relationship between evidence, explanation and theory. • The role of controversies, disagreements and processes of certification (peer review) in science.	• Collaborative and collective nature of the scientific work.	"I learnt about how scientists collaborate and how they need to research different species to develop the theory of evolution."
		• Relationship between evidence and theory.	"I learnt that scientists collaborate to get more evidence for their scientific theory, so there is a higher chance of their theory being good."

Table 11. Expected NOS learning objectives and students' responses to their NOS diaries in each lesson of the Evolution TLP (cont.)

Lesson	Expected NOS aspects	Trends from students' diaries (outcomes)	Example of quotes about NOS from the diaries
3	• Social and cultural influences in the production of scientific knowledge. • The role of controversies, disagreements and processes of certification (peer review) in science. • The relationship between evidence, explanation and theory.	N/A[117]	N/A
4	• The relationship between evidence, explanation and theory. • The relationship between science, ethics, economics, environment, intellectual property, etc.	• Relationship between evidence, explanation and theory.	"Scientists do further research so they can know more about what they are talking about."
		• Connection between science and society.	"I learnt about their [scientists] connection with society, and how debate and look for evidence."
		• How animals can become extinct.	-

[117] When students' diaries are not available that means there was not enough time at the end of that lesson for them to work on this instrument.

Table 11. Expected NOS learning objectives and students' responses to their NOS diaries in each lesson of the Evolution TLP (cont.)

Lesson	Expected NOS aspects	Trends from students' diaries (outcomes)	Example of quotes about NOS from the diaries
5[118]	• The relationship between evidence, explanation and theory. • The relationship between science, ethics, economics, environment, intellectual property, etc.	• Relationship between evidence, explanation and theory.	"Scientists work by looking for evidence to explain how animals become extinct."
		• How animals can become extinct.	-
6	• The role of controversies, disagreements and processes of certification (peer review) in science. • The relationship between science, ethics, economics, environment, etc. • The relationship between evidence, explanation and theory.	• Collaborative and collective nature of the scientific work and processes of certification in science.	"They [scientists] don't always agree. But if they joined their ideas they would be more successful."
		• Relationship between science and environment.	"Scientists work on trying to figure out ways to preserve animal life." "I learned about how science helps us to understand what happened to different species."
		• Techniques to preserve biodiversity.	-

[118] Lessons 5 and 6 were added to the original lesson plan; they were dedicated to, respectively: Extinction (continuation of lesson 4, which was originally lesson 3), and continuation of Extinction followed by Biodiversity (originally lesson 4).

An initial analysis of these tables reveals that most NOS aspects expected to be explored by the TLP were in fact identified by the students as something they had learnt during those specific lessons. In the case of the Medicines TLP (table 9), for instance, students wrote about the importance of collaborations, trials, evidence, natural resources and biodiversity to our knowledge about medicines. Similarly, their diaries from the Evolution TLP (table 11) displayed the expected impact of these lessons on their talk about scientific evidence and theories, and collaborative work and peer review in scientific communities.

Nevertheless, in the case of the Magnetism TLP (table 10) students' diaries tended to focus more on learning of content than about NOS. Two reasons can be attributed to this scenario: the limitations of the instrument of data collection itself and/or issues with the TLP (its development and teaching). In the first case, reflection is needed upon how students understood the question informing the writing of these diaries ("what did you learn today about how science and scientists work?"). It is possible that during their work on the diaries they had been focusing on the first part of the question ("what did you learn today"), which can account for the large number of mentions to content-related aspects (e.g. types of magnetic materials, what magnetic field is, usages of magnets, etc.). In order to try and remedy this situation, teacher F and I started to reinstate the whole meaning of the question from lesson 2 onwards. The partial effects of that can be seen in their diaries from lessons 2 and 3 and in the following TLP (Evolution), in which mentions to NOS aspects started to appear more consistently.

There is also the case of how the expected content and NOS aspects were presented by teacher F during these lessons; as previously discussed, he shifted his discussions about NOS around the different lessons during the Magnetism TLP. It is worth noting how when he actually had a lengthy discussion with his students about NOS aspects, such as in the cases of collaborations and exchanges in science during lesson 2 and the relationship between science and technology during lesson 3, this was also reflected in their diaries. In the latter case, while talking about the development of the compass by the Chinese, teacher F returned to the discussion about science and technology from lesson 2 and they had a long conversation about building this instrument and scientific knowledge. This may be the reason why, even though not originally planned for lesson 3, as seen in table 10, ideas about this relationship between science and technology appeared in their diaries at the end of this lesson.

In this scenario, it is also important to highlight that the time spent by teacher F on the whole class discussions about content and NOS aspects had a significant impact on students' diaries not only during the Magnetism TLP, but also in the

Medicines, Evolution and Earth’s resources lessons. As expected, tasks and follow-up questions involving NOS aspects that were rushed through had little influence on what students opted to write in their diaries. In other words, those ideas about NOS that were less (or not) explored explicitly appeared less in what students wrote about these lessons.

That was the case, for instance, of task 1 from the Medicines TLP (figure 22 in chapter 6), in which students were expected to compare herbal and conventional medicines and decide which one they would use. Since teacher F did not have time to carry out the whole class discussion around the follow-up questions planned for this task, the NOS aspects expected to be explored at that moment (table 9, lesson 1 – “Understand and evaluate scientific claims through evidence and testimony”) were absent from students’ diaries.

Similarly, lesson 6 of the Evolution TLP, which focused on biodiversity, should have explored ideas related to ethics, intellectual property and financial aspects of science not only when discussing different methods for preserving biodiversity, but also during task 6: “What do we preserve when we aim for 'biodiversity'?”. During this task, students had to work on a preservation case (figure 23 below) to discuss the different perspectives (local, global, financial, environmental, etc.) involved in preserving biodiversity based on the follow-up discussions below:

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 organisation, one private person?

4. Can you think about any negative impact of this scheme on the lives of the local people? What can it be done about it?

5. Can you think about any negative impact of this scheme on the local environment?

Imagine yourself as an ornithologist working in the tropics. You meet a wealthy patron of preservation - someone who has purchased tens of thousands of acres to conduct research on innovative sustainable agriculture. This local magnate (whose fortune comes from owning a national fizzy pop company in England) is an avid birder. He wants to rescue the dwindling population of hyacinth macaws, whose habitat is shrinking due to deforestation of the rainforest in South America. These magnificent, impressive birds nest in the hollows of old trees, so that even if new trees are planted to replace the forests, the old trees and nesting sites are still lost. The situation is aggravated because the local people are poor enough that they are motivated to capture the birds and sell them to traders who smuggle them and market them to wealthy bird collectors. This patron wants a scheme to take macaws from the wild, raise them in captivity and release them on his own land, establishing a protected population on his "nature preserve". What do you think about this idea? Can you think about pros and cons to it?

Figure 23. Hand-out for task 6 (Evolution TLP)[119]

[119] Image credit: Ken Barber.

Whole class discussions about positive and negative aspects of techniques for preserving biodiversity and about the follow-up questions related task 6 were, however, rushed through at the end of lesson 6 by teacher F (one of the few moments he did that during this TLP). The effects of this decision are illustrated by the absence in students' diaries of one NOS aspect expected to that lesson: "The relationship between science, ethics, economics, environment, etc." In summary, and in alignment with other research about NOS teaching and learning (Abd-El-Khalick & Lederman, 2000; Deng et al., 2011; Fouad et al., 2015), there was a link throughout this experience between the absence of explicit discussions about some NOS elements and what students deemed as learning outcomes from these lessons.

Another relevant source of information about students' engagement with NOS aspects was the mind map, developed at the end of each TLP with one focus group of four-five students (different groups for each TLP). The aim of building these maps was to stimulate students' reflection about what they had learnt about how science works throughout their study of Medicines, Magnetism, Evolution and Earth's resources, and how those ideas are interconnected with the development of scientific knowledge about these topics – as done by Kim and Irving (2010) in their research about high school students' views of NOS. This group work was of unstructured nature (i.e. not guided by specific pre-planned questions) and generated one mind map about each TLP[120], such as the one seen in figure 24 below, for the Medicines topic.

[120] In each map relevant areas related to NOS aspects are highlighted with different colours; for each map, the colour scheme is also linked to its subsequent analysis and to illustrative quotations from students' conversations during this group work.

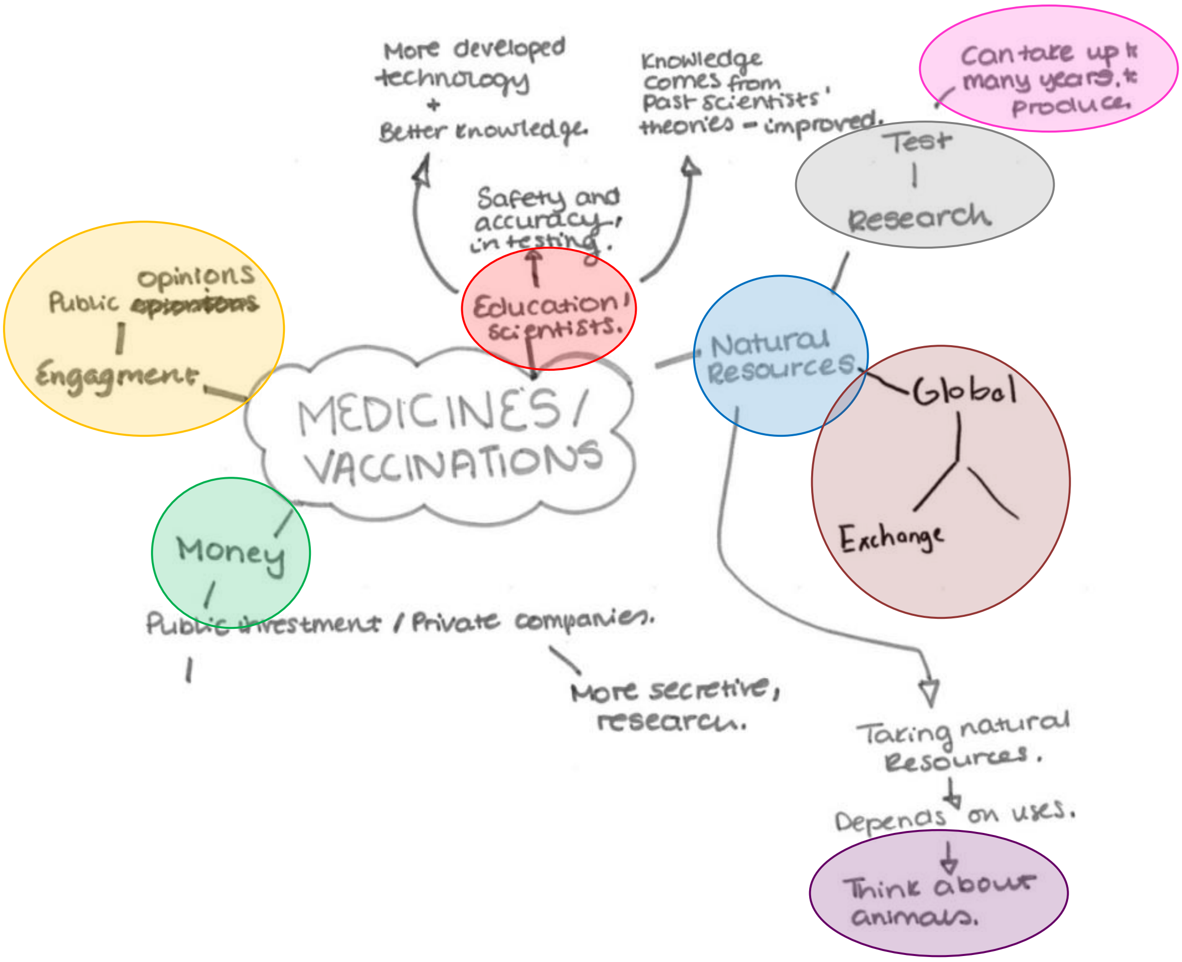


Figure 24. Group mind map on Medicines (after-TLP)

When looking at this map, different ideas related to NOS can be noticed: the financial aspects behind medicines production **("money")**, the use of **natural resources**, and **knowledge-related** ("education, scientists") and **public engagement** ("public opinions") aspects. Looking more closely at these ideas, we can see students' thoughts about how money is related to science and the question of public and private investments and of secretive research; how medicines development is dependent on natural resources and how it can **impact on nature** ("think about animals"); how this process is based on **long-term and costly research** (see also quote from their group work below); how previous knowledge, **exchange of knowledge between different people**, and testing are important parts of this development to ensure safety and accuracy (see also quote from their group work below); and how this process is subject to the influence of public opinion.

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, or if there are like consequences**.”

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.”

Student J: “I also think **it depends on how reliable the test is**.”

Student I: “If the resource is very dangerous, **you have to test it again and again to make sure it’s ok.**”

Going back to table 8, we can see how many of the NOS elements expected for the TLP were explored in this map, such as: “The importance of natural resources for the production of scientific knowledge and the consequences of their exploration (including environmental issues and intellectual property in science)”; “Collaborative and collective nature of the scientific work”; “The relationship between science, ethics, economy, politics, etc.”; and “The role of experiment, controlled investigation and quality control in science”.

Other ideas, on the other hand, seemed to have escaped these students when producing this map. The aspect “Understand and evaluate scientific claims through evidence and testimony”, for instance, is not present in this map nor in students’ diaries. This can imply that students might have not developed a full picture of this specific NOS idea during the teaching of this topic, and an explanation can be drawn from teacher F’s need to rush through some tasks and follow-up questions, such as those involved in task 1 from this TLP (also seen in figure 22 in chapter 6). This result then highlights the relevance of explicit teaching of NOS to students’ active engagement with these ideas.

The Magnetism map (figure 25 below) also includes different aspects related to NOS, such as: the relationship between magnetism and **technology** (“many people used before it was explained”); the impact of this **technology on society** (e.g. “war”, “safety”, “trading”, “migration”, “politics”); **indirect observations** in science (“invisible but see the effects”); the **natural aspect of magnetism** (“natural phenomenon” and “magnetism is around us”). When comparing this map with the expected NOS aspects for this TLP (table 8), some of them can be correlated: “Social and cultural aspects of science (commercial aims, contextual influences, exchange and transmission of knowledge)”; “The importance of observation and indirect evidence in Science”; and “The relationship (and differences) between Science and Technology”.

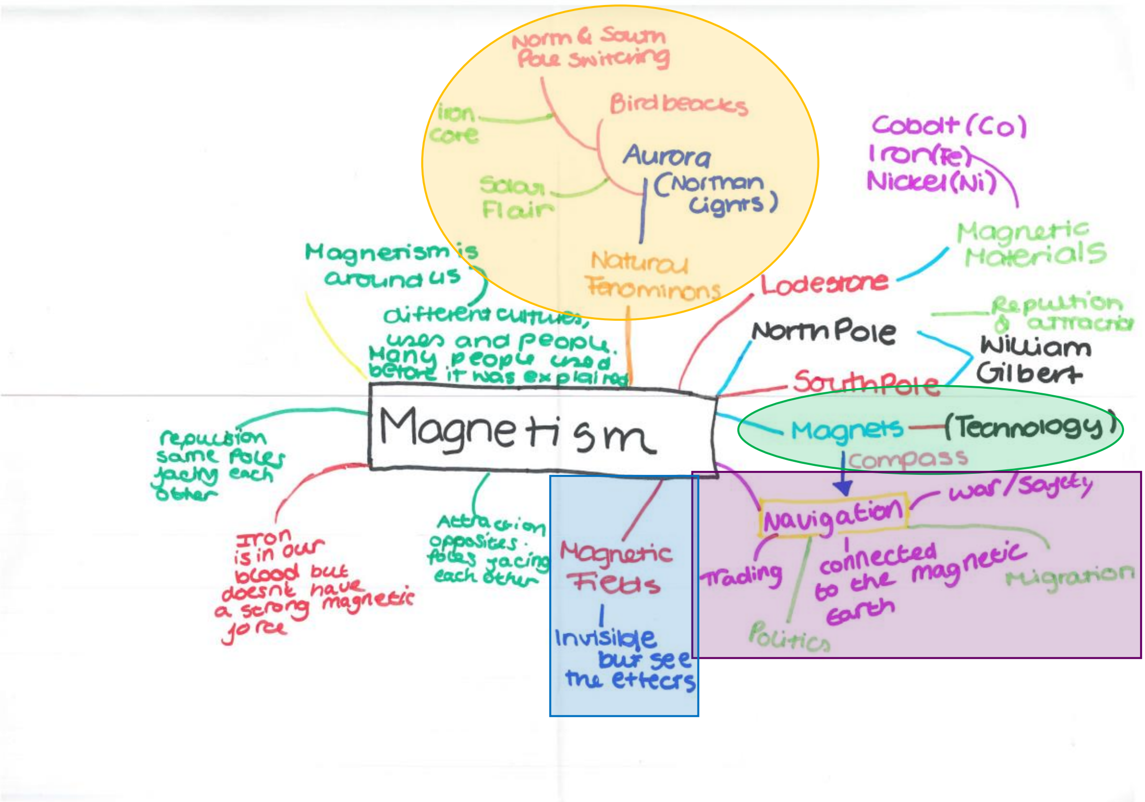


Figure 25. Group mind map on Magnetism (after-TLP)

The other two ("Science is tentative, creative and does not answer all the questions; and "The role of modelling in science"), however, have not been addressed by both this map and students' diaries. As argued for the Medicines TLP, the absence of these specific NOS aspects can be associated with the amount of time dedicated by teacher F to explicit explorations about these ideas. That was the case, for instance, of modelling in science, which was to be explored during their lesson on William Gilbert's and Mary Somerville's works on magnetism and magnetic fields (see appendix 18). These specific narratives, having been placed, respectively, at the end of lesson 3 and right before the practical in lesson 4, ended up being rushed through by the teacher, with little time employed to their explicit teaching.

On a different note, it is worth noticing how this Magnetism map includes not only NOS aspects, but also the original content expected by the KS3 scheme of work (as also seen in the quote from their group work below about the uses of compass). This result highlights the possibilities offered by the choices made throughout the development phase and discussed in chapter 6 (such as the use of narratives grounded on the intercultural model and the explicit questioning approach) to the integration between scientific content and NOS elements, especially in the case of topic less traditionally related to NOS such as Magnetism.

Researcher: “I see here that you have navigation. Why?”

Student L: “**North pole and south pole.**”

Researcher: “Ok, why?”

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.**”

Student N: “The magnetic force of the Earth is not strong enough to pull us down, but **it’s strong enough to guide the compass**.”

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 like, 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: “Because **they can travel and advance their knowledge about things even further**.”

Students’ mind map on the Evolution topic (figure 26 below) also includes different NOS elements mainly linked to theories and evidence, such as: the collaborative **and collective nature of scientific work** and its processes of certification (“sharing evidence”); the relationship between **evidence and explanation** in science (“theory – evidential explanation”); the **continuous nature of the development of scientific theories** (“work – continuous”; and “keep linking ideas”). These ideas are also illustrated by a quote from their group work below.

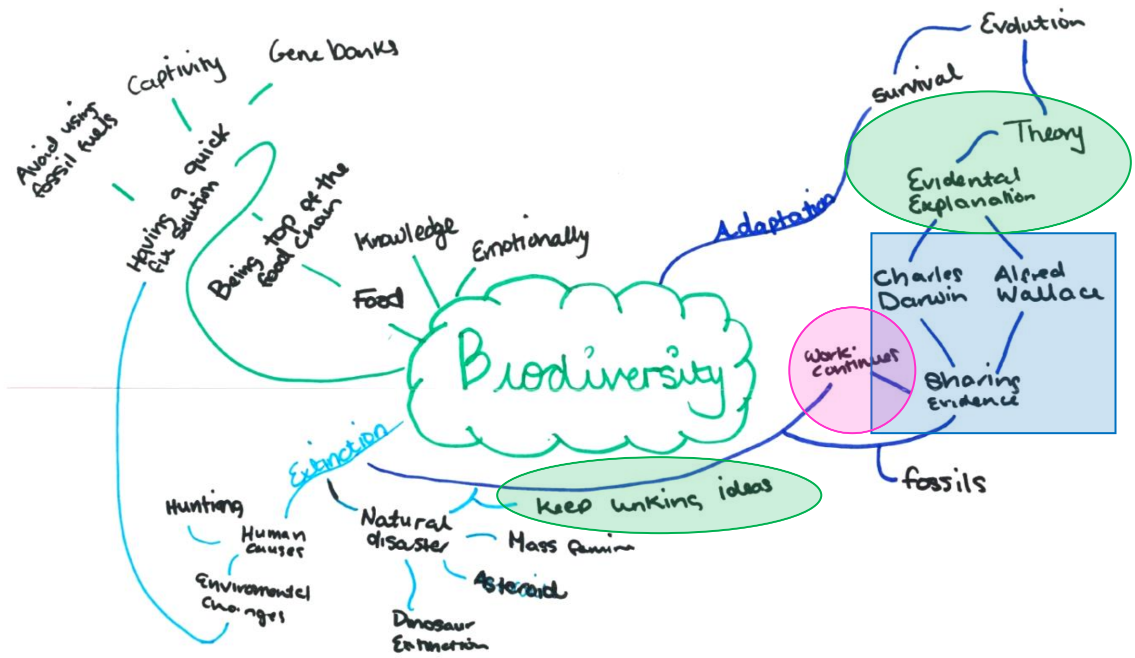


Figure 26. Group mind map on Evolution (after-TLP)

Researcher: "So what do you mean **when you say theory** here?"

Student O: "It's an educated **explanation of what's happened in the past and might happen in the future.**"

Student P: "It's an **explanation based on evidence**."

Student Q: "Yeah, people gather different evidence and develop an explanation for something they are investigating. **Like Darwin and Wallace**."

Researcher: "Is finding evidence all you need to do?"

Student R: "You have to **show your ideas to other people, like scientists**."

Student O: "**Explaining to other people**."

Student Q: "**You need to keep working on it**, and other people will share more evidence and ideas about the topic."

Although many aspects in this map can be clearly associated to NOS ideas expected for this TLP (table 8), some are still missing, such as: "The relationship between science, ethics, economics, environment, etc."; and "Social and cultural influences in the production of scientific knowledge". Once again, this result can be connected with the time spent by teacher F on tasks and follow-up questions specially elaborated to address these NOS aspects. That was the case, for instance, of the already mentioned task 6 (on the preservation of hyacinth macaws), in which discussions about the relationship between science, ethics, economics and intellectual property were only briefly explored at the end of the lesson.

On the other hand, the aspect "social and cultural influences in the production of scientific knowledge" was thoroughly delved into by teacher F alongside his students during their conversation about eugenics and science, including their discussion about 'rational decisions' and its relationship with society. Thus, its absence on the map cannot be correlated with a lack of time to have explicit discussions about it during the lessons, but it can be linked to issues in the original TLP. One possibility here is a non-explicit association between evolutionary ideas and this discussion about eugenics and rational decisions. In other words, the fact that evolutionary ideas were not originally associated with eugenics by the narratives explored in this TLP prior to this moment of the lesson might have broken the long narrative that was being developed around evolution and natural selection since the beginning of the topic, leaving this specific discussion about eugenics isolated in the TLP. This case illustrates the importance, as argued in chapter 6, of a coherent narrative for the whole TLP if we aim at integrating NOS aspects into the teaching of regular content.

Figure 27 below displays the final mind map produced by the students during this Implementation phase and it is related to the Earth's resources TLP. As with the other maps, ideas linked to NOS aspects that were part of this TLP (table 8) can be identified here, such as: "The relationship (and differences) between Science and Technology" (e.g. "**not enough technology** back as they want to dig deeper to find more information about it"; "recycling is a social concern because there would be no technology [without metals]"), "The relationship between science, ethics, economics, environment, etc." (e.g. "[recycling because] **we don't have enough, some metals are or hard to extract**"; "extraction [of metals] is **expensive**, [it involves] carbon and heating, [impacting on] global warming), "Science is tentative, creative and does not answer all the questions" [e.g. "want to dig deeper to find more information about it"; "hard to extract"; "[electrolysis] has to be under control"), and "The relationship between **natural resources and science**" (e.g. "can we find metals everywhere?"; "harder to find"; "rock"; "mining").

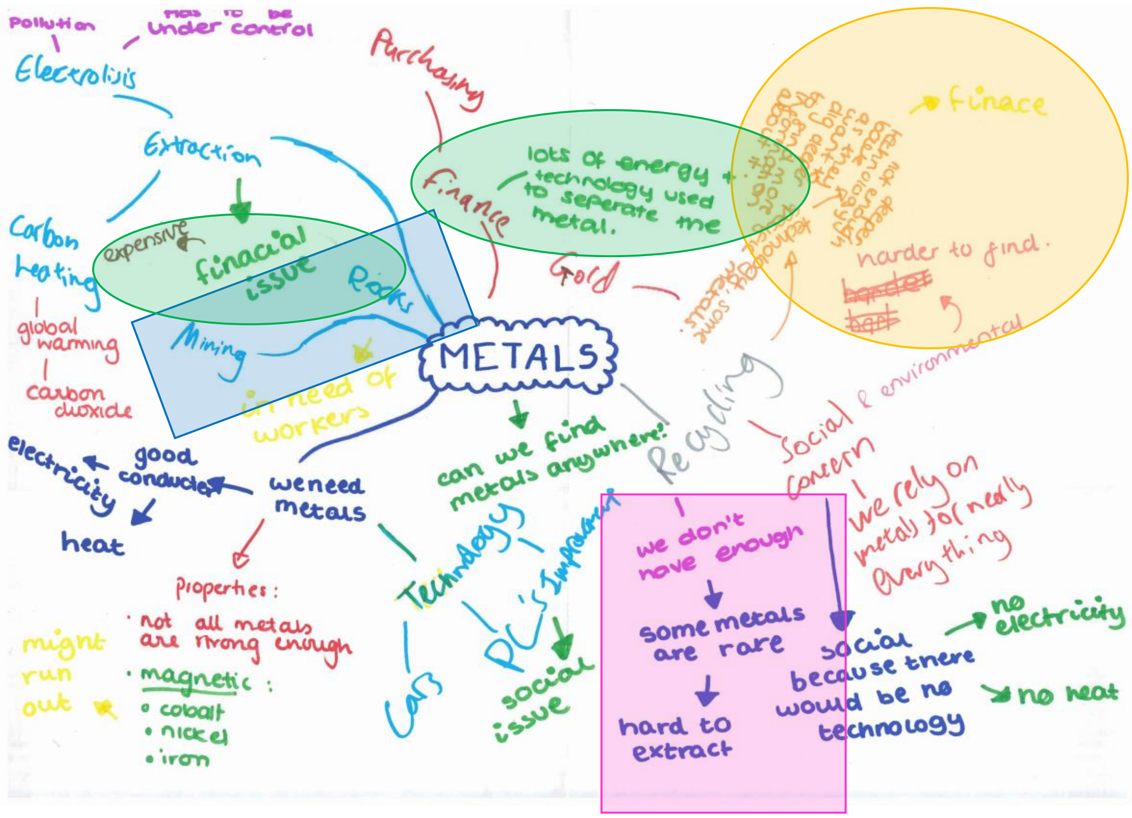


Figure 27. Group mind map on Earth's resources (after-TLP)

Other ideas such as "Collaborative and collective nature of the scientific work" and "Social and cultural aspects of science (commercial aims, contextual influences, exchange and transmission of knowledge)" were underexplored in this map. Interestingly, while teacher F had developed some of these ideas during his lessons 1 and 2 (introduction task and interactive map), students seem to have chosen to focus on more technical, social and environmental aspects when working on this map. This can be related to the connection between this topic and SSIs, which was the basis, as mentioned in section 6.1, for the development of this TLP. Since our aim here was to move Chemistry lessons away from a purely microscopic, procedural and memory-based approach to a more 'global' and critical perspective, the results from the map are possibly a reflection of this choice made at the development stage.

Nevertheless, the adoption of the 'spiral' approach throughout this whole experience allowed for the exploration of similar NOS elements in different TLPs and, thus, these 'missing' aspects from this Earth's resources map can actually be found on the maps and discussions carried out during the Medicines and Magnetism focus groups. This approach seems to have enabled teacher F to overcome, at least to some extent, the lack of discussions about NOS in some instances by having other (past or future) opportunities to work on these elements in different lessons and TLPs.

On a final note, it is worth noticing how, when working in these focus groups, students had a lot more to talk about than when they had been writing in their diaries. This can be connected with their own learning experiences throughout these TLPs, where pairs and whole-class discussions informed their engagement with NOS aspects. Obviously, I must recognise here my influence on the production of these maps, since some unstructured prompt questions I asked while they were thinking about these topics could have led them to include specific aspects in their maps. However, this is not necessarily a negative feature of these activities, considering that the whole process of collectively thinking about and discussing NOS is in itself a great learning opportunity for them and research opportunity for me.

These results also show the complementary relationship between these two of methods of data generation chosen to investigate students' engagement with NOS topics during the teaching of the TLPs. Considering how some NOS aspects mentioned above did not fully appear in the map, but were part of their diaries in different moments, we can infer that the choice of tracking students' understandings of NOS aspects by using daily diaries and a final summarising task was positive.

The effects of the TLPs on students' ideas about NOS were also investigated at the end of the school year. One of the questions in the post-Implementation HOS questionnaire (1d – see appendix 12), for instance, asked them to think about: "what are the main things you learnt about how the scientific community and scientists work?". Among the 13 answers received for this item, 12 were related to views of science as process (for instance, about collaboration and exchanges between scientists and communities), as illustrated by three students below:

> "I learnt about how they share ideas, where and how they work, and how they produce and introduce their theories."
> "Scientists work together to share their ideas but sometimes they have challenges while doing that."
> "I learnt that scientists work together and collaborate to produce better theories."

A more in-depth investigation of these ideas about NOS was also carried out through the application of the NOS questionnaire (see appendix 9) in a pre/post-Implementation style, as seen in most studies around experiences with explicit teaching about NOS (Deng et al., 2011). As done for the analysis of this instrument during the Exploratory phase, students' answers were coded through an inductive process and organised in the form of networks through the use of ENA, which are displayed by figures 28 (pre-Implementation) and 29 (post-Implementation), with their main features summarised by table 12 below.

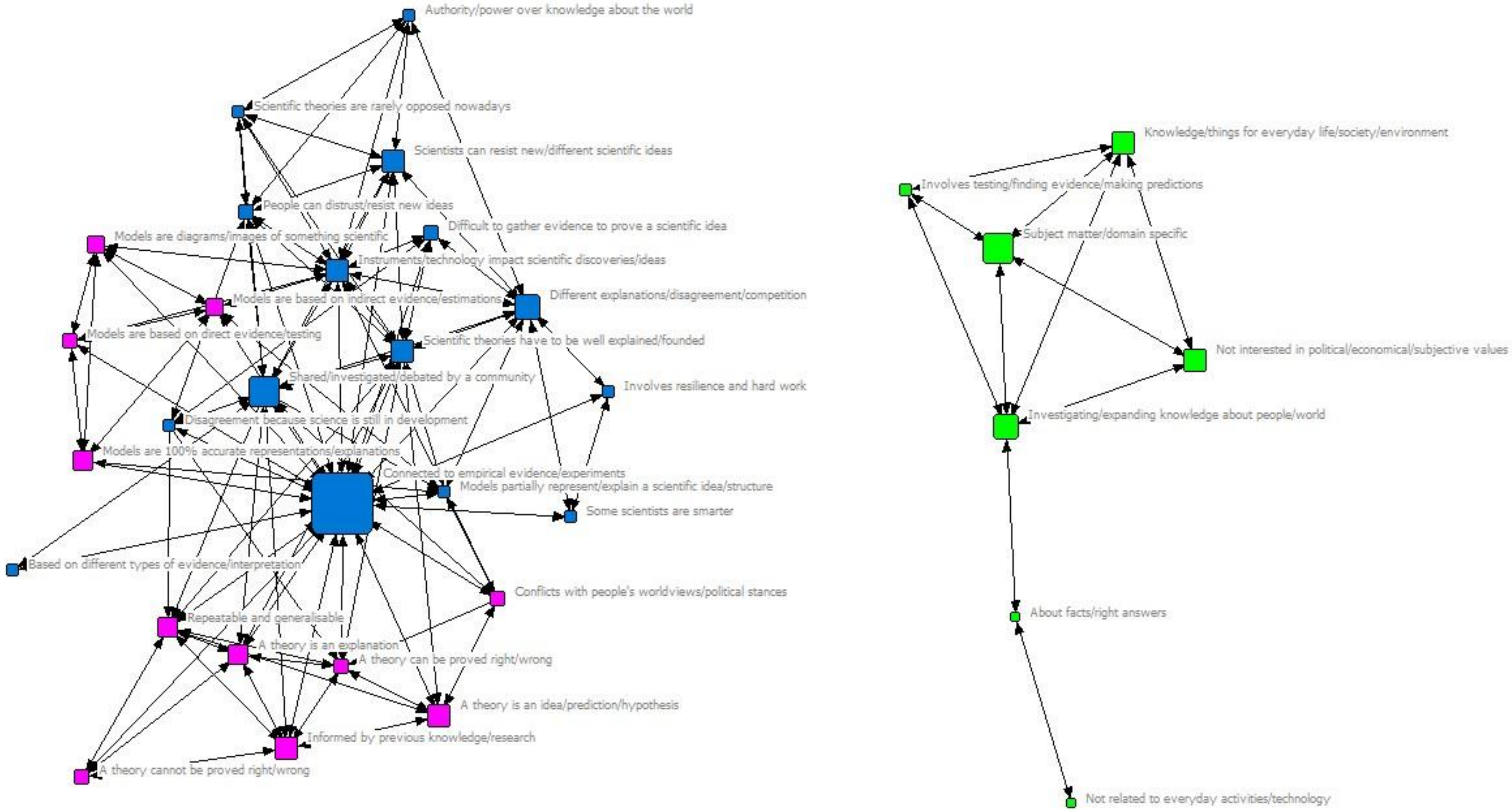


Figure 28. ENA of students' answers to the NOS questionnaire (pre-Implementation) (n = 24)[121]

[121] The colour scheme refers to different clusters of statements: pink = models & theories; green = purposes of science; blue = production of scientific knowledge.

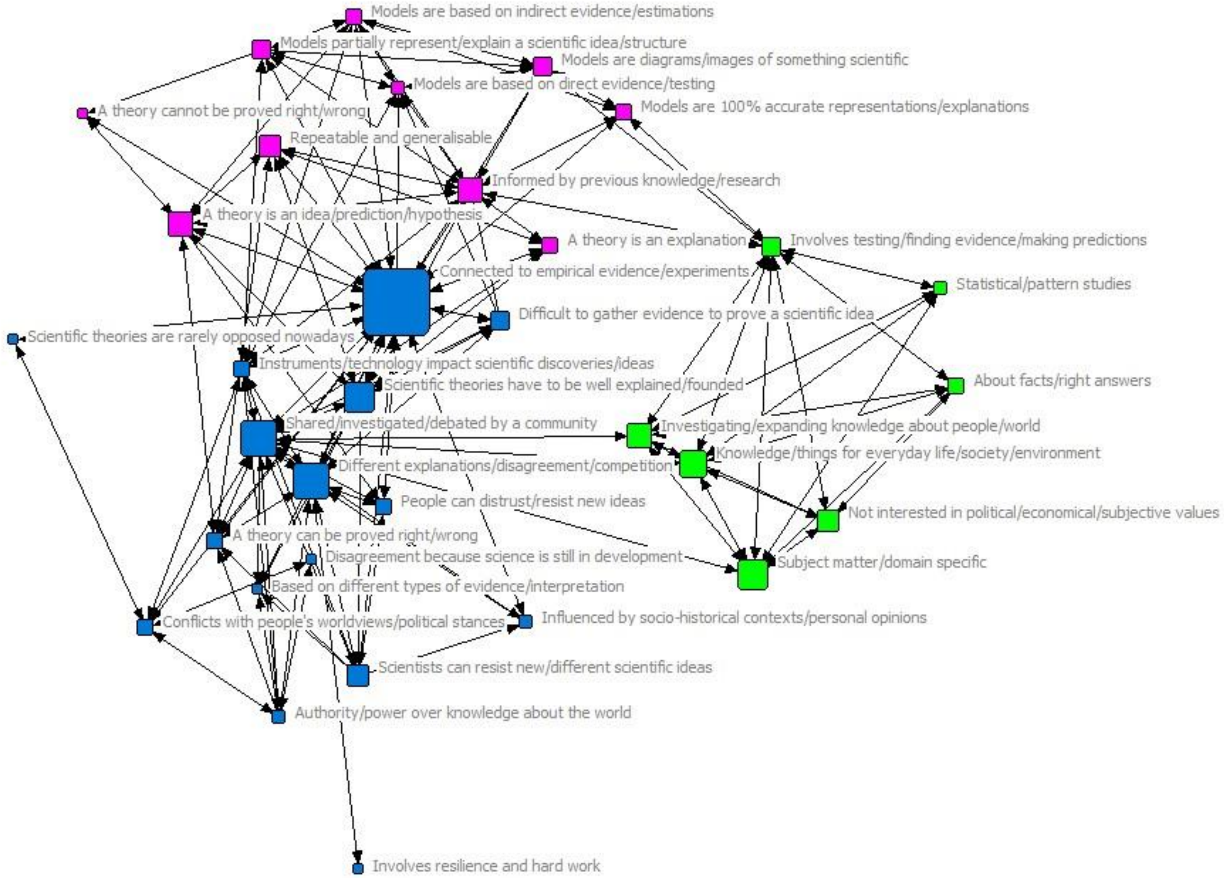


Figure 29. ENA of students' answers to the NOS questionnaire (post-Implementation) (n = 25)[122]

122 The colour scheme refers to different clusters of statements: pink = models & theories; green = purposes of science; blue = production of scientific knowledge.

Table 12. Main features of the epistemic networks about NOS produced by the participant class (pre and post-Implementation)

Stage	# statements	Density of the network (%)	Most frequent statements (size of nodes)	Most central statements
Pre-Implementation	33	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 • Scientific theories have to be well explained/founded • Science is a subject matter/domain specific
Post-Implementation	33	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

The general results obtained from these questionnaires show an increase in the complexity of students' ideas about NOS after the Implementation phase: while both coding processes (pre and post) generated the same amount of statements (33) about how science works, the difference in density values (18.8% and 22.1% for pre and post-Implementation networks, respectively) highlights a rise in connections between different ideas employed to produce these answers. When compared to the results obtained from the nine participant groups during the Exploratory phase, these numbers also show a notable impact of the Implementation phase on how students answered questions related to NOS: while the pre-Implementation figure (18.8%) was close to the numbers obtained by the other two year 8 groups (17.2% at school A and 17.4% at school B), the post-Implementation result (22.1%) was the highest found among all NOS questionnaires applied at both phases, even in relation to KS4 top set groups (19.8% and 20.8% for year 9 set 1 at school A and year 10 set 1 at school B, respectively).

The effects of this experience can also be seen in the most frequent and in the most central statements in the two networks. While some statements continued to be frequent to their thinking about NOS (e.g. "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"), new statements acquired more importance after this phase in comparison (e.g. "There can be different explanations, disagreement and competition among scientists"; "Scientific theories have to be well explained/founded"). In addition, the number of statements in central positions also increased, implying a more diverse view of which ideas are important when talking about NOS. This is closely related to the rise in the density figure, since the more connections students make between different ideas about NOS, the more 'central' these interconnected ideas become.

Another relevant aspect of these networks is that while the pre-Implementation one is very similar to the ones obtained at the Exploratory phase, the post-Implementation network brings to the front statements that had not been previously relevant to students. That is the case, for instance, of statements in the 'Purposes of Science' cluster (coloured green): while "Science is a subject matter/domain specific" still got considerable mentions after the experience, "Science involves investigating and expanding knowledge about people and the world" and "Science develops useful knowledge/things for everyday life, society and environment" increased in their importance – not only in their frequency of use (size of the node), but also in their centrality to these answers, that is, in how relevant they are to students' views about the purposes of scientific work.

As discussed in chapter 5, moving away from a view of scientific questions and work that is solely grounded on subject matter (e.g. Chemistry, Physics, Biology) to one that considers producing knowledge as central implies a change to a view of science as a process. Nevertheless, "Science develops useful knowledge/things for everyday life, society and environment" is still a utilitarian view of science (Solomon et al., 1996; Kang et al., 2005), a result that can be related to how the TLPs were developed to include examples about the importance of science to everyday life knowledge and objects, an approach much valued by teachers and students in the Exploratory phase. Interestingly though is the fact that even these 'utilitarian' views of science became more connected with process-based statements (e.g. "Science involves testing, finding evidence and/or making predictions"; "Scientific ideas are shared/investigated/debated by a community of people") and with the 'Production of scientific knowledge' cluster (coloured blue) when compared to the pre-Implementation network.

In this scenario, one possible impact of the TLPs can be linked to the further development of these everyday life examples, which were not employed solely through an illustrative approach, as seen in the Exploratory phase, but were in fact analysed and discussed in relation to knowledge and material production by science and technology through contextualised in-depth approaches. The notable approximation and the establishment of connections between the 'purposes of science' and 'production of scientific knowledge' clusters in the post-Implementation network through process-based statements then hints to the positive effects of explicit and in-depth approaches to examples employed in school science on views about NOS, as argued throughout this project.

Another relevant finding when comparing the two networks is related to the specific statement "Scientific theories and models can be informed by previous knowledge/research on the topic": while present on the periphery of the pre-Implementation network, this statement acquired a central position on the 'Models & Theories' cluster (coloured pink) in the post-Implementation map, also establishing a high number of connections with the two other clusters. This outcome highlights possible effects of the TLPs on how students view the production of ideas (e.g. models and theories) in science, going beyond the sole focus on empirical aspects (e.g. evidence) to also include notions related to construction of scholarship, exchange of knowledge and background/collective research. The increase in importance of other statements in the 'production of scientific knowledge' cluster when compared to the node about empirical evidence/experiments also hints to a more complex and social view about science and its nature [the 'social explanation' approach, according to Driver and colleagues (1996)], now involving the social-institutional aspects that were central to these TLPs.

Statements related to the relationships between science and ‘external’ social-institutional aspects, such as Economics and Politics, continued to be few and peripheral in the post-Implementation network (e.g. “Scientists and their work can be influenced by socio-historical contexts or personal opinions”), even if more closely connected with central ‘knowledge production’ statements than on the pre-Implementation network. These ideas were, however, found in some students’ diaries, in parts of their mind maps and during our post-Implementation final interview, as illustrated below. This indicates possible limitations of the NOS questionnaire in addressing some specific NOS aspects more directly. The use of different methods to investigate these views was then, as already discussed here, important to the understanding of the effects of the TLPs on students’ views about NOS.

> Student D: “In Earth’s resources we learned about **how different metals are more expensive, because it’s harder to remove them from the minerals**. So if they work with it in some specific technology, it is more expensive.”
> Student F: “Also for Medicines, **some of them were really expensive back then because the resources to produce them took a long time to find**.”
> Student E: “The rarer the resource [for Medicines and minerals] is, like a plant or a metal, the more expensive it is, **because not a lot of people could access it or use their properties, whereas the common these resources become, the cheaper it would be**.”

In summary, the main impact of the TLPs on participant students seems to reside on understanding science as a process of knowledge production that involves exchanges, collaborations, long-term work and that is related to different aspects of society. The increase in the complexity of students’ answers to the NOS questionnaire, going beyond a narrow focus on gathering large amounts of evidence [‘empirical explanation’ approach – Driver and others (1996)], and the interconnectedness between their views on NOS and the content they had been learning throughout this experience then highlight the importance of explicit and integrated approaches to the inclusion of discussions about how science works in science lessons.

In addition, the use of an intercultural model to HOS to inform the development of the TLPs was expected to generate narratives about scientific work that included a more balanced and interconnected exploration of epistemic and non-epistemic aspects of NOS, a necessary change to current NOS proposals advocated in this project and by other researchers (Erduran, 2014; Erduran & Dagher, 2014; Aragón-Méndez, Acevedo-Díaz & García-Carmona, 2018; Ideland, 2018). As illustrated by the rise in importance (centrality and citations) of some statements related to this dimension in the post-Implementation network[123], and by the integration of these elements into their mind maps, diaries and discussions about NOS, this model seems to have positively impacted students' engagement with the social-institutional dimension of NOS. This scenario illustrates the possibilities offered by the intercultural model to the work with a more holistic and balanced view of NOS.

One specific rationale that informed the decision of using the intercultural approach to develop these TLPs – namely, the introduction of more diverse examples from HOS into science lessons – still needs to be addressed here though. While not directly related to RQ4 and not an immediate expected learning outcome from the TLPs, an intercultural, mode diverse and historically-informed approach to the organisation of and discussions carried out in their science lessons could also impact, at least to a certain extent, students' knowledge about diversity in scientific development.

As discussed in chapter 5 about the findings from my Exploratory phase, students tend to hold very narrow view about who scientists are, which can impact, among other things, their views about NOS and that 'scientists are not like us'. I then argued that HOS could help counteracting this over-emphasis on traditional (and mostly Eurocentric) views about scientists and scientific development exactly through the adoption of more culturally diverse approaches such as the intercultural/global perspective. To investigate these possibilities, the HOS questionnaire developed for this research (seen in chapter 2) was applied in a pre/post-Implementation style to the participant students, being further explored during my final interview with a group of them. Figures 30 and 31 display their answers to Q1, Q2 and Q3 in the HOS questionnaire pre and post-Implementation, respectively. Meanwhile, figures 32 and 33 display their answers to Q4 and Q5 pre and post-Implementation, respectively.

[123] Such as: "Science develops useful knowledge/things for everyday life, society and environment"; "Scientific ideas are shared/investigated/debated by a community of people"; "There can be different explanations, disagreement and competition among scientists".

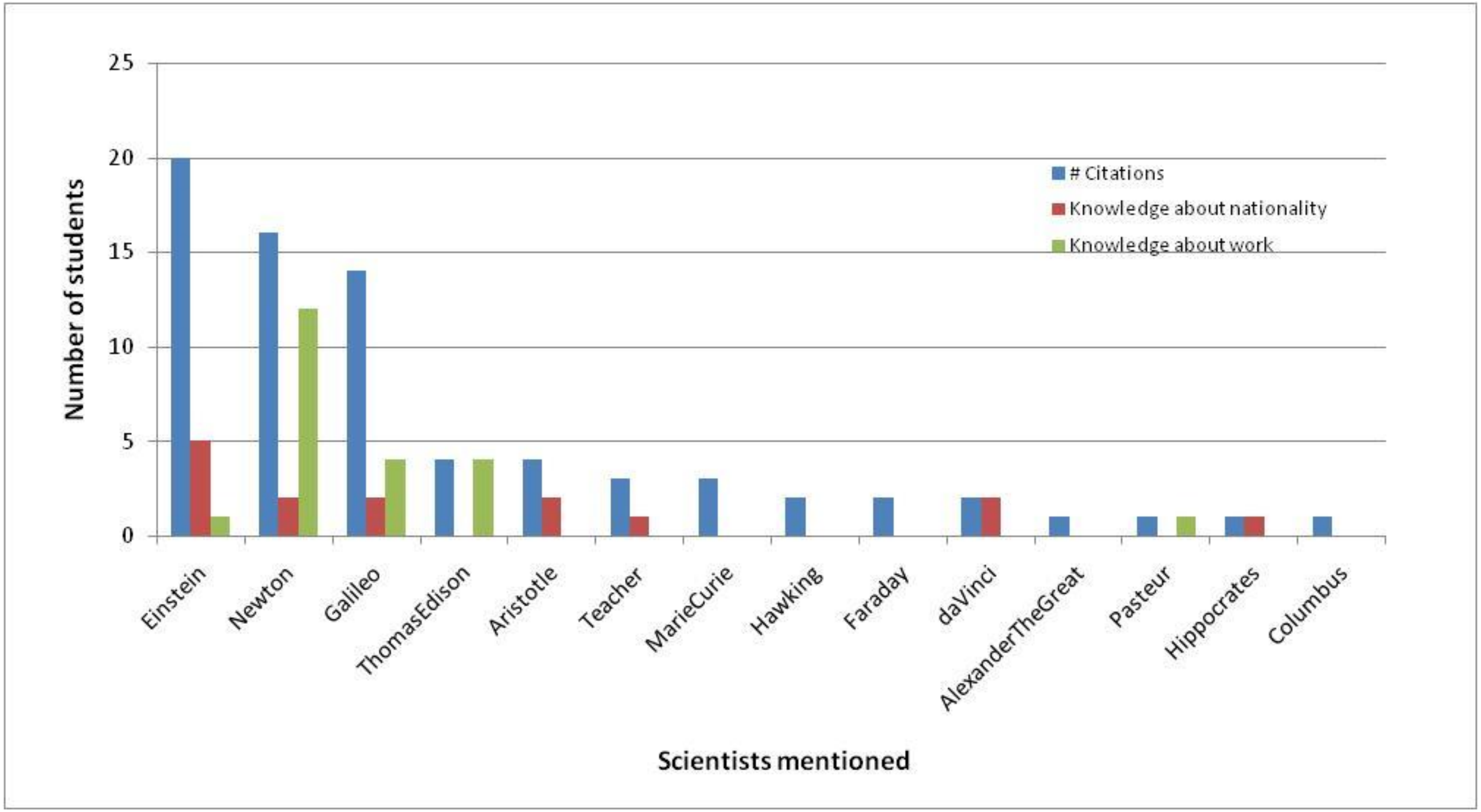


Figure 30. Scientists mentioned by the participant students – pre-Implementation (Q1+Q2+Q3) (n = 26)

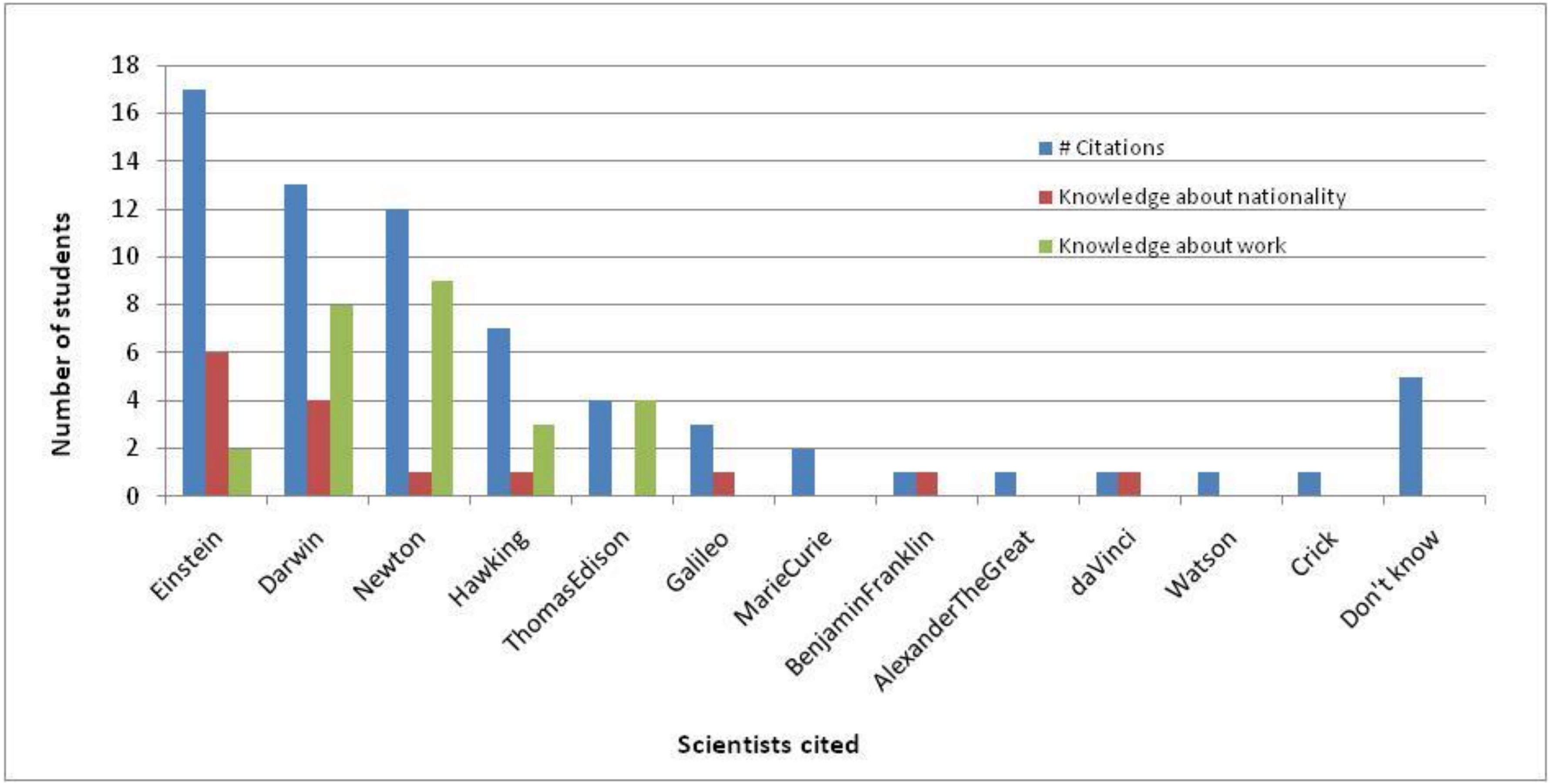
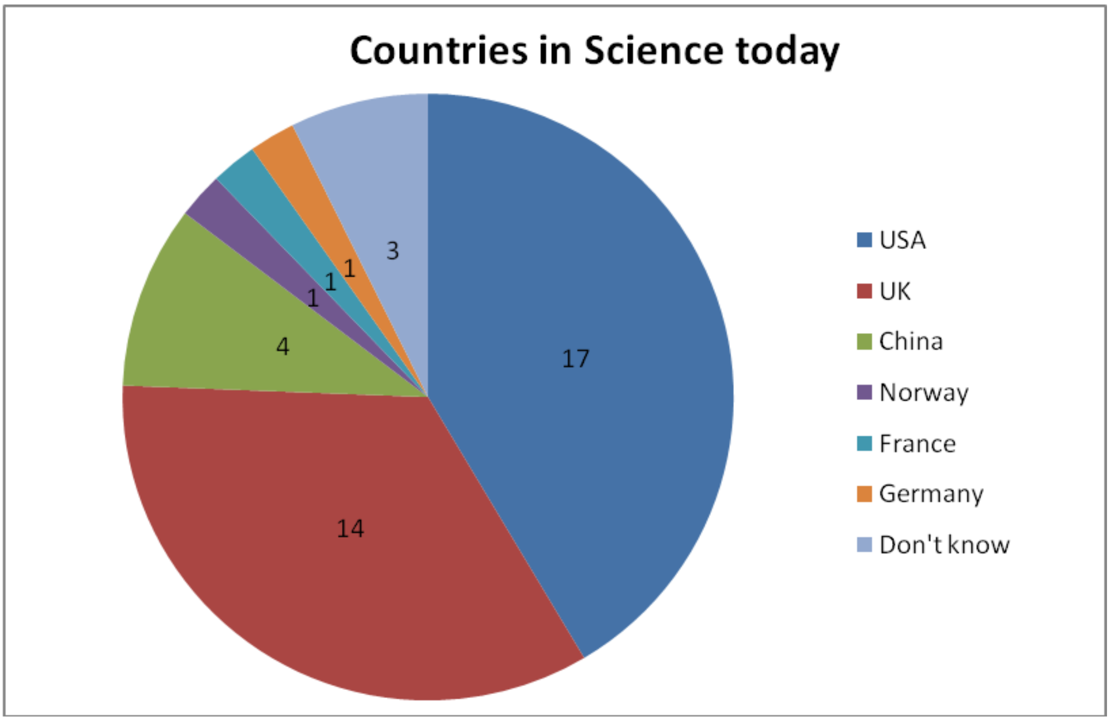


Figure 31. Scientists mentioned by the participant students – post-Implementation (Q1+Q2+Q3) (n = 25)



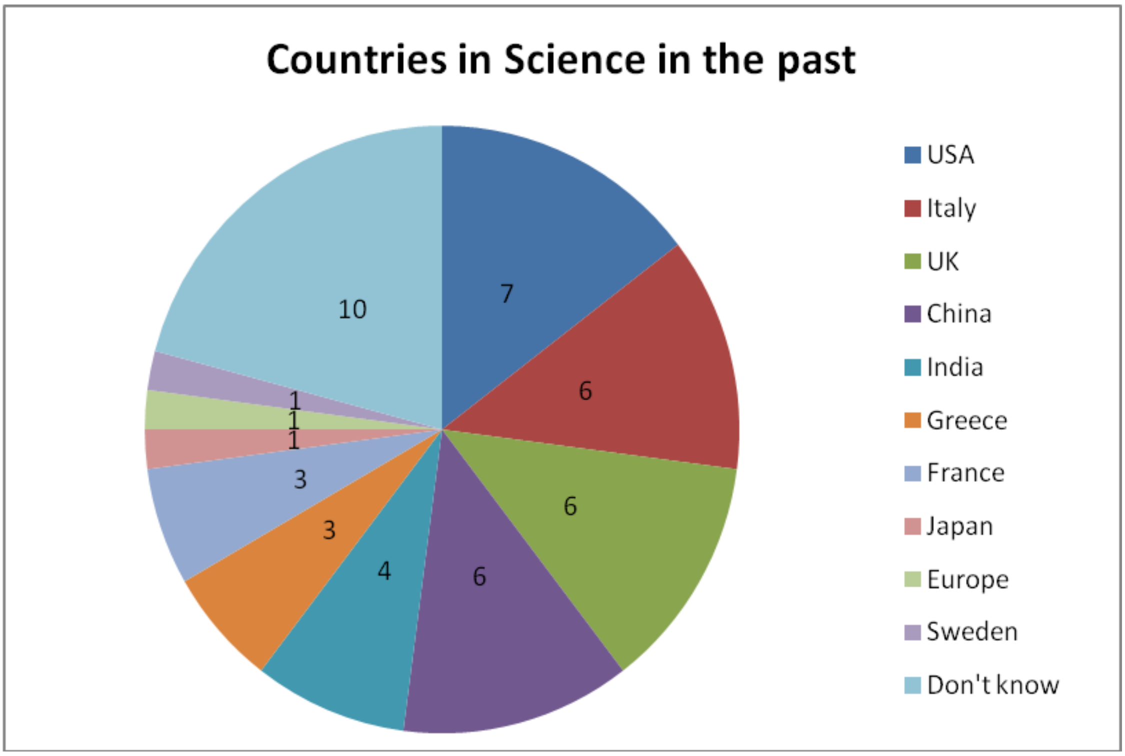
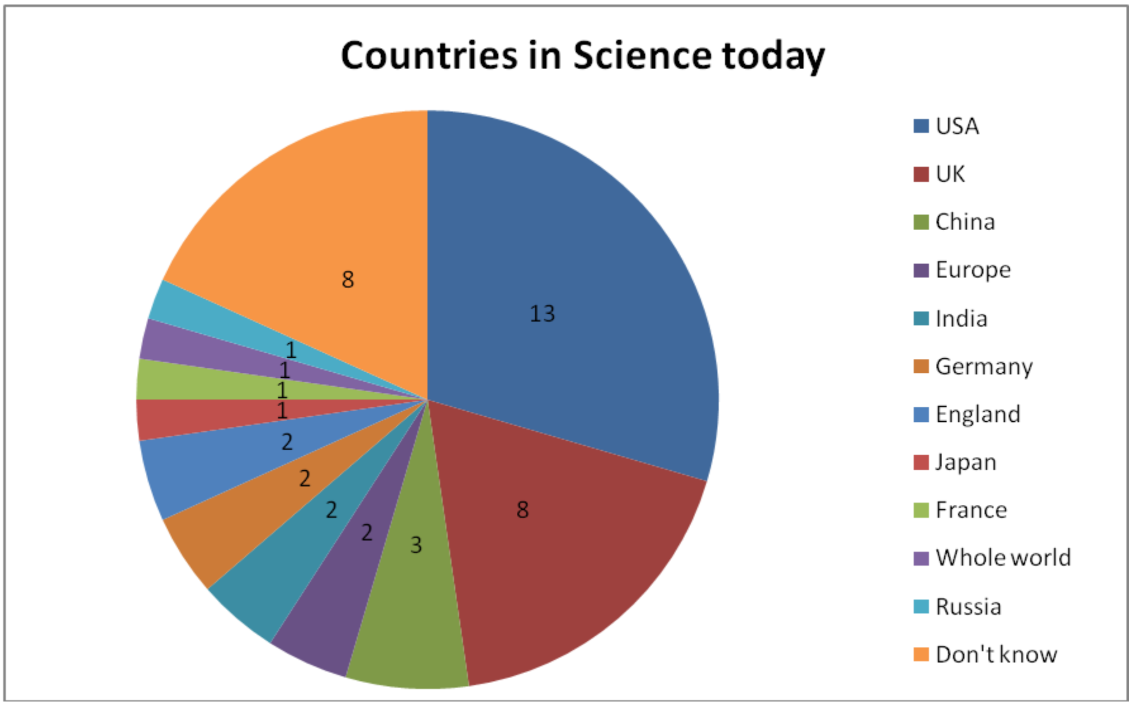


Figure 32. Countries mentioned by the participant students – pre-Implementation; (a): countries nowadays (Q4); (b): countries in the past (Q5) (n = 26)



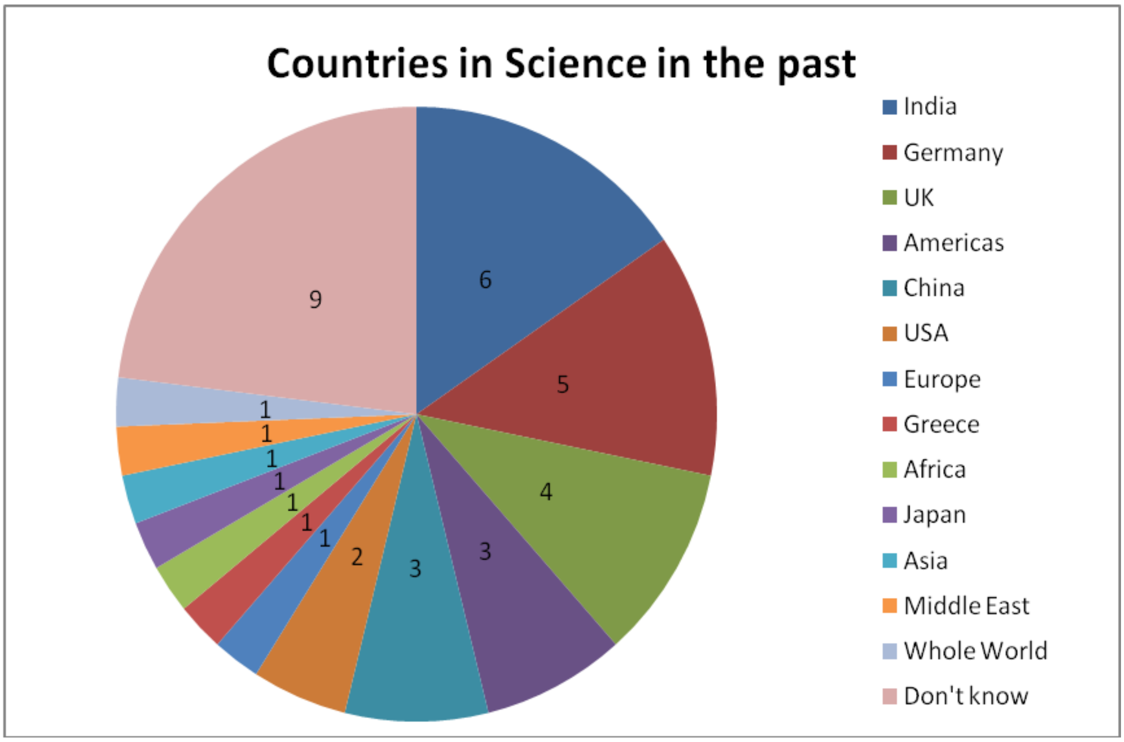


Figure 33. Countries mentioned by the participant students – post-Implementation; (a): countries nowadays (Q4); (b): countries in the past (Q5) (n = 25)

Looking at the results related to scientists (figures 30 and 31), few changes in students' answers can be detected after the implementation of the TLPs (except for Darwin being the second most cited after this experience). Also, most scientists explored by the TLPs were not remembered by the students in the post-Implementation questionnaire. That was the case, for instance, of Mary Somerville in the Magnetism

TLP, Mary Montagu in the Medicines TLPs, and Alfred Wallace in the Evolution TLP. Interestingly though, all these scientists were mentioned by them during our final focus group not by name, but by achievement/work (e.g. “that was the case of that woman who saw inoculation in Turkey and then brought the knowledge about it to Britain” or “there was that slave in the US who knew about inoculation because they did that in Africa”).

This scenario can hint to not only the persistent presence of very specific images of scientists (e.g. Einstein and Hawking[124]), but also to possible limitations of the HOS questionnaire to evaluate students’ knowledge about different people’s contributions to science. As argued in chapters 4 and 5, there are clear constraints in a memory-based questionnaire, and results from this Implementation phase highlight the importance of interviews to grasp a better understanding of students’ actual knowledge about a certain topic.

Therefore, during these interviews the impact of the in-depth approach to the examples employed by teacher F on students’ engagement with HOS became clearer. Despite not remembering these diverse scientists’ names, they were aware of their contributions to developments in science and were able to connect these people and their achievements with the narratives developed in the lessons. As advocated by other researchers (Wang & Marsh, 2002; Allchin, 2004; Clough, 2011), results from this phase bring to light the relevance of contextualised and in-depth elaboration of historical examples in science lessons to students’ engagement with and learning from the historical narratives proposed.

In chapter 4 I discussed how the limitations of the HOS questionnaire regarding the memory-based questions about scientists could be partially overcome by the questions added to investigate students’ views on different countries’ contributions to science. A comparison between pre and post-Implementation answers to Q5 (countries in the past) illustrates, at least to some extent, this possibility: there was an increase in the diversity of countries cited by the participant students as contributors to the development of scientific knowledge throughout history, with new citations (e.g. Americas, Asia, Africa and Middle East) and with a gain in relevance of other countries (e.g. India and China) in relation to European countries and the USA.

This is a positive result when considering that one of the original aims of this experience was to include more diverse examples into science lessons to increase students’ awareness of different communities’ contributions to science. The impact of the intercultural narratives on how students view participation in science were more clearly seen during our final focus group, where they highlighted that they had learnt

[124] Newton, also found in this post-Implementation results, was explored throughout that school year by their other science teacher.

about how science is done by several groups of people instead of being an individualistic endeavour:

> Student D: "I think people forget, like, **it's not just one person, it's a lot of people in different places working on many ideas.**"
> Student F: "It's interesting to learn science like that."
> Student E: "**It was more diverse than we were used to**, so it's interesting to learn about that."
> Student H: "I like it because **we didn't really know about that**; before it was only 'that guy from Europe', but **we never thought about other people working on science, like people from Africa or China.**"

Therefore, besides aiding the integration of NOS aspects (especially those of social-institutional nature) into the teaching of regular science content, the TLPs seem to also have impacted, to a certain extent, students' awareness of more diverse contributions to scientific development. This specific result highlights the affordances that scholarship about the Global History of Science can bring to Science Education, as suggested by recent articles in the field (Orthia, 2016; Lee, 2018). Furthermore, it shows how the support for teachers in the planning and in-depth exploration of diverse examples in science lessons can result not only in productive discussions about NOS, but also in bringing the 'diversity in science' debate to the realities of regular lessons and curricula at the secondary level.

Lastly, different researchers (Leach et al., 2003; Clough, 2006; 2018; McComas, 2008; Taber, 2008; Toplis, 2011; Allchin, 2012b; Forato et al., 2012) argue that teaching about NOS aspects and content in regular science lessons can (and should) be done in an interconnected way, with these goals interweaved in the same proposal, such as in these TLPs. Some (de Berg, 2014b; Clough, 2018), however, have recently criticised empirical studies with NOS-based activities and lesson plans for their lack of consideration of the impact of these proposals on students' results in official exams. That is, while the majority of NOS research tends to focus on evaluating the effects of activities on ideas about NOS, very few (e.g. Irwin, 1999; Kim & Irving, 2010; Patano & Talas, 2010) take an extra step to also analyse impact on content learning (as measured by official exams), including whether these approaches can worsen students' performances due to a 'sharing of time' between content and NOS.

Therefore, the final aspect of the learning level to be discussed here is students' marks in their end-of-year exam. Data were gathered in this study to evaluate possible positive, negative or neutral effects of the TLPs on students' marks in their final exam, which encompassed the topics explored throughout this phase. The average mark of the participant year 8 group was of 38% (n = 26; SD = 18%) against an average of all other year 8 groups at school A of 33% (n = 178; SD = 18%). This group of students also ranked first among all year 8 groups in that year when considering only their average marks, with 3% above the average mark from the group ranked in second place.

Although the standard deviations of both samples are very high, making most statistical comparisons unlikely to result in a significant difference between these two averages[125], we can at least infer a non-negative impact of this experience on participants' performance in this exam. More importantly, prior to this year-long 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 behaviour issues identified within the group in the previous year and to their marks in their final exam at the end of year 7, which were the lowest in their cohort.

Thus, seeing these students positively engaged with the lessons and with teacher F, and achieving such a positive result in their exams in year 8 when compared to their starting point at the beginning of that school year indicates the potential of a thorough integration between NOS and curricular content: it can afford the development of more explicit and engaging class discussions about scientists and scientific work without losing sight of the curricular and assessment constraints and pressures faced by science teachers. Through careful and collaborative work between researcher and teachers, science lessons can be contextualised, diversified, and enriched through the use of diverse examples and tasks, and of in-depth discussions, and still properly function within the general expectations promoted by regular curricula.

7.3. Final comments about the Implementation phase

The main goal of this Implementation phase was to explore the possibilities and limitations offered by the intercultural model of HOS to the teaching and learning about NOS, as summarised by RQ4: "In which ways can an intercultural model of HOS be successfully integrated into school science through TLPs to foster teaching and learning of NOS?".

To address this question, I then investigated the development and teaching of TLPs around the topics of Medicines, Magnetism, Evolution and Earth's resources by teacher F in his year 8 group at school A (RQ4.1: "How can the planning and teaching of these TLPs be carried out to promote the integration of NOS into school science?)", along with the impact of these TLPs on students' views on NOS and interactions with

[125] A t-test (2-tail), for instance, shows no significant difference between these two averages, with $t(202)=0.06$, $p=0.05$.

their science lessons (RQ4.2: “In which ways can this approach impact students’ understandings of NOS and what are their views about this experience?”). Inspired by CR perspectives, I aimed at understanding this experience from a multi-layered approach, exploring the relationships between different dimensions (development, teaching and learning), participants (e.g. students, teacher F and myself as a researcher), choices made during this research phase (e.g. topics, teaching strategies, historical narratives) and structural aspects at the school (e.g. curriculum and assessment) and the academic (e.g. scholarship in the HOS field) levels.

In relation to the development and teaching dimensions of the TLPs (explored by RQ4.1), some crucial aspects were identified throughout this experience:

- The existence/absence of a HOS scholarship based on an intercultural/Global History approach;
- The use of narratives (‘storylines’) to promote a ‘spiral’ exploration of similar NOS aspects in different lessons and among different TLPs;
- The relevance of an intercultural approach to the promotion of a balanced work between epistemic and social-institutional NOS elements;
- The effects of collaborative work between researcher and participant teacher on teacher’s ownership of these materials and professional learning;
- The pedagogical possibilities of a question-answer approach to promoting explicit and in-depth discussions about NOS and to its connection with scientific content.

While these mains findings about the development and teaching of the TLPs have already been discussed in chapter 6, the specific CR perspective adopted in this study means that these dimensions were expected to be intrinsically linked to the students’ dimension explored in the present chapter. Therefore, the analysis of the impact of the intercultural model of HOS on students’ understandings about NOS cannot be dissociated, for instance, from the historical-epistemological and pedagogical choices made at the other two dimensions. Some findings related to this students’ perspective then illustrate the connections between these decisions and their engagement with the lessons and NOS, such as:

- The narratives were positively received by students, who praised the use of different and stories and tasks throughout the lessons. These narratives also allowed for the integration between NOS and scientific content, without lowering their exam results and increasing their explicit engagement with NOS aspects.
- The question-answer approach was also positively received by these students, who especially enjoyed the opportunities to share and discuss ideas. This strategy, coupled

with the aforementioned narratives, also resulted in an explicit and integrated exploration of NOS aspects throughout the lessons.

- The 'spiral' approach offered these students the chance to engage with similar discussions about NOS at different times, allowing them to establish connections and revisit these ideas throughout the school year. According to teacher F, this approach impacted their participation in the lessons and confidence in talking about science, as well as the depth of these discussions, as seen especially in the focus groups, mind maps and lesson observations.
- The intercultural model of HOS employed in the development of the TLPs resulted in an increase in number and depth of social-institutional aspects found in the post-Implementation NOS network and in students' mind maps, diaries and discussions about science carried out throughout the year.

In summary, we can consider the impact of these TLPs developed through an intercultural model of HOS as positive. It affected students' interactions with teacher F, content and NOS aspects, which resulted in a generally constructive experience for them (and their teacher), not only in terms of learning, but also in relation to their behaviour and engagement, as highlighted by teacher F during our final interview:

> Teacher F: "It's interesting how **they worked well together** [during this experience]. […] You can definitely see that. Like I said before, the group of students who are not particularly good at getting along, they were really well-behaved overall. **By the end of this course, they were giving contributions and respecting each other's contributions**. […] The year before we would have had the case of someone coming from the break or in period 1 shouting and that was all I would be dealing with for the whole hour. And I know they still have their issues, but actually these lessons lend themselves very much to the students kind of engaging in a work mode, and focusing on the discussions and tasks for that hour."
>
> Researcher: "And why do you think that happened?"
>
> Teacher F: "Maybe that's because **the lessons were much more engaging**. There was always **a ritual**, you know, **it was a coherent format all the time**, so students **knew what to expect** and knew to be and **how to participate**. There was no uncertainty for them […]. And that's down to the planning of the tasks and the questions for the discussions."

Chapter 8: Final thoughts and Conclusions

In this final chapter the findings from both Exploratory and Implementation phases will be summarised and further discussed with the aim of re-addressing the research questions proposed in this study. In section 8.1 I will look more closely at the Exploratory phase, drawing conclusions about relevant aspects involved in NOS teaching and learning, use of HOS in school science and diversity in science lessons, and about the implications of this phase to the next stage of this study – the development and implementation of the TLPs.

In section 8.2 I will then explore lessons learned from the Implementation phase, with special attention to the three dimensions investigated throughout this study: development, teaching and students. Starting from the impact of the TLPs on students' learning and interest in these lessons, I will address the connection between these findings and the different steps taken and choices made at the development and teaching levels, from historical-epistemological, pedagogical and teacher's perspectives. The specific role of the teacher in this study will be further addressed in section 8.3, where thoughts about professional development, perceived self-efficacy and ownership of educational change and their links with curriculum and resources development will be explored.

Lastly, in section 8.4 I will offer a critique of this study, re-examining some of my methodological choices and limitations of both research phases. Suggestions for future research and implications for the different fields involved in this project (e.g. HOS, NOS, educational innovation) will be finally explored in section 8.5.

8.1. Examining HOS and NOS in school science – lessons from the Exploratory phase

My aim with the Exploratory phase was to generate a better understanding of schools' realities in relation to NOS teaching and learning, use of HOS and inclusion of diverse examples into science lessons. In addition, as an international researcher with little experience of the English educational system, this year-long phase supported my familiarisation with said research context, including its organisation, members (teachers and students), curriculum and accountability processes. The three research questions explored throughout this phase then aimed at building an overall picture, even if limited by its small scale, of the scenario of NOS teaching and learning and use of HOS in urban secondary state schools, and the findings related to these questions (discussed in chapter 5) were also relevant to the development of the Implementation phase.

RQ1 – “What are the possibilities and obstacles found in teachers’ practices and realities for the inclusion of intercultural aspects of science into school science?” – was explored through observations of science lessons and interviews with participant teachers about their use and types of examples, interactions with students, and work around socio-scientific issues, applied science and NOS. The main finding from this stage alluded to a restricted use of specific types of examples by the teachers: while they were generally creative in connecting the topics with different examples close to students’ realities (mostly everyday objects and appliances), this work was mainly done through an illustrative approach, that is, through a superficial mention of these examples without any further discussion or analysis.

This illustrative approach to the use of examples then impacted how teaching about NOS happened during these lessons. While potential cases involving these topics were present in a good number of lessons observed, the amount of time and discussion dedicated to their explicit, more contextualised and in-depth examination with the students was reduced, with a greater focus on conceptual knowledge and work on exam questions.

These initial findings were further explored alongside the participant teachers throughout our interviews, and relevant patterns surfaced from their experiences of school science. Their use of an illustrative approach and the lack of further examination of potential NOS aspects that could emerge from some lessons were not related to an unawareness of the importance of these ideas to school science; on the contrary, all participant teachers seemed conscious of that. Nevertheless, the familiar time constraints, assessment pressures, perceptions of students’ abilities and lack of resources to develop this type of work (Höttecke & Silva, 2011; Ryder & Banner, 2013; Turkenburg-van Diepen, 2013) were pointed out by these teachers as mediators of how they explore examples, SSIs, NOS, HOS and other ideas in their lessons, being the main ‘obstacles’ identified to the inclusion of the intercultural model of HOS into their practice during the subsequent Implementation phase.

We can infer that what it is needed is not necessarily a change of teachers’ beliefs about NOS, SSIs and HOS, but actually a change in teaching reality and opportunities (Guskey, 2002). In other words, it became clear from this Exploratory phase that since the participant teachers seemed open to innovative ideas and to making their lessons more challenging, the issue for the Implementation phase would be less about promoting educational change through the modification of participant teachers’ beliefs about, for instance, NOS (Goodson, 2003; Fullan, 2007) and more about promoting this change through the development of new knowledge and practices within the constraints of their specific realities – the 'change environment' (Clarke & Hollingsworth, 2002).

On the positive side, these teachers' openness to interactions and engagement with their students' ideas, interests and opinions, when time was available for it, was a relevant finding from this stage to the development of the Implementation phase. The specific theoretical approach to NOS and HOS advocated in this project – holistic, critical, dynamic and negotiated rather than a list of fixed ideas/concepts – naturally required more open and dialogic teacher-student interactions. Therefore, integrating a more in-depth examination of scientific work through the intercultural model into science lessons seemed to have found a pedagogical ally in these teachers' practices: their willingness and interest in promoting more active participation from their students in the lesson dynamics. While these interactions were mainly a result of teachers' initiations, students seemed comfortable with contributing when asked. Along with teachers' beliefs in the potential of NOS and diversity to their lessons, this finding was relevant to the integration of the intercultural model of HOS into school science to be attempted in the subsequent research phase.

During this Exploratory phase, students' own ideas about HOS and NOS were also investigated in the form of RQ2 ("In which ways are participant students aware of the history of scientific development carried out by different people in different places of the world? What can be influencing and shaping their awareness?") and RQ3 ("What are participant students' main understandings about NOS? What can be influencing and shaping these understandings?"). Inspire by a multi-layered approach to the analysis of these RQs, it was my aim here to explore the possible effects of their teachers' practices around NOS and HOS on how students perceive the development of scientific work throughout our history. The rationale here was then to understand the mechanisms influencing, even if at a small scale, students' images of scientific work to be better equipped for the work on TLPs.

Results from the HOS and NOS questionnaires and my follow-up interviews with these participant students showed, as expected, the effects of practices observed in the lessons on how they talk about scientific work. For instance, we can infer a connection between the lack of in-depth and diverse use of historical and contemporary narratives about science and their superficial view about who scientists are, how science can be done on a global scale and how that impacts knowledge development. As argued by several researchers (Allchin, 2004; Erduran, 2014; Forato et al., 2015), HOS can do much more for school science than simply being used as a background story for a specific content or as memory-based practice, giving a check-list of important scientists. If used as such, instead of achieving its much-advertised potential of humanising science and scientific work, HOS is in danger of becoming a simple add-on to the already packed school science, with no real benefits to broadening students' understanding of the scientific world.

Students' overreliance on evidence when answering the NOS questionnaire and in our interviews, with very little awareness of its social-institutional aspects and their relationship with epistemic aspects, can also be connected with specific curricular and school science practices, such as the greater focus on epistemic ideas (e.g. experimentation and reproducibility) when NOS was part of the observed lessons and when it was explicitly addressed by teaching resources and assessment. More importantly, the general implicit approach to NOS observed in most lessons – with few moments of actual discussion about these ideas – seemed to have left a lot for these students' imagination, and as such many missed opportunities for lesson enrichment with the use of HOS.

While these results about students' views of HOS and NOS have already been found by similar research in the field (e.g. Driver et al., 1996; Rudge et al., 2014; Fouad et al., 2015), very few projects (e.g. Gurgel et al., 2014) so far have attempted to connect questionnaire and interview findings with actual teaching realities as done in this Exploratory phase. What I am arguing here is that identifying 'lapses' or 'inadequate' aspects in students' or teachers' views about NOS (e.g. Lederman et al., 2002; Kessels et al., 2006) is not enough to inform future changes in school science practices.

As advocated by researchers on NOS teaching (Taber, 2008; Clough, 2018), we need to know more about how these views are interconnected with class routines. That is, we need a multi-layered approach that considers the role of teachers in these scenarios, not only in relation to their views and attitudes towards the topic (e.g. NOS, HOS and diversity) but also to teaching approaches adopted during the lessons. Identifying practices that promote (e.g. explicit in-depth discussions promoted, for instance, by planned follow-up discussions) and those that are less effective (e.g. implicit, illustrative and stand-alone approaches) in fostering knowledge development about NOS was then of great relevance to this project, and in keeping with my CR approach, findings from these three research questions are seen here as intrinsically linked to personal (teachers' views and beliefs, students' views), professional (teachers' practices, choices and strategies) and structural/institutional (national curriculum, assessment, time management of curriculum) dimensions.

Furthermore, according to Fullan (2007), educational change should not be seen simply as a change in teachers' beliefs about a topic (e.g. teaching about NOS) or as the use of new teaching resources (e.g. the TLPs developed here), but also as a change in teaching strategies (e.g. use of planned questions, spiral curriculum, in-depth examples) coordinated with the other two dimensions. And this multi-layered approach to change is only sustainable if the conditions and mechanisms involved in teachers' practices and students' views prior to the implementation of innovative materials are known and understood in all their interconnected nature. My view here then is that several of the obstacles to the introduction of NOS and HOS into school science singled out by these studies emerge exactly from the superficial understanding of the realities of specific research contexts (schools) and participants – more specifically, of the class routines, teaching strategies and choices, and their connection to views on HOS and NOS. Therefore, the Exploratory phase was not only useful to understand the connections between students' views on HOS and NOS, teachers' practices and curriculum, but also to identify possibilities and obstacles to the introduction of the intercultural model of HOS into regular science lessons during the Implementation phase.

Clough (2018), while reflecting about research on NOS teaching and learning after decades of projects developed around this topic, pointed out that we still need a better understanding of successful mechanisms and strategies to promote NOS in practice among teachers and to help them overcome the well-known constraints to this type of innovative work. In this scenario, I finish this section by arguing that not only was a close work with teacher F during the elaboration of the TLPs relevant to the use of these resources in his lessons (to be further discussed in the next sections), but also my engagement and learning from his and other teachers' realities and practices throughout this Exploratory phase.

8.2. Bringing the intercultural model of HOS to school science – the Implementation phase

The main aim of this project was, since its initial conception, to promote a more dynamic, holistic and culturally diverse integration of NOS aspects into regular school science. The adoption of the intercultural model of HOS to inform the development of the TLPs was then connected not only to providing students with opportunities to talk and learn about scientific work and community, as done by other research, but also to employ more diverse examples/narratives in these lessons, as recently advocated in the field (Erduran, 2014; Sarukkai, 2014; Ideland, 2018). This goal was summarised by RQ4: "In which ways can an intercultural model of HOS be successfully integrated into school science through TLPs to foster teaching and learning of NOS?"

Therefore, the original focus of this investigation was on the students: the impact of this approach on their interaction and enjoyment of their science lessons; its affordances for discussions about NOS; and its effects on their knowledge about diversity in science. And, because of that, my final look at the Implementation phase will start from them – the students dimension – as informed by RQ4.2: “In which ways can this approach impact students’ understandings of NOS and what are their views about this experience?”

Firstly, it is important to remember here the small-scale nature of this study – one year 8 group of 26 students at school A – and acknowledge that the findings discussed in chapter 7 are bounded to this specific scenario. On the other hand, while some of these results might have not been achieved with other groups of students, promising indicators of the potentialities of the intercultural model for future research on teaching and learning about NOS can be singled out. That is the case, for instance, of students’ enjoyment of the whole-class discussions carried out by teacher F. As argued in chapter 7, most students in this phase highlighted these conversational moments as one of the most enjoyable parts of their lessons informed by the TLPs, something they had not previously experienced in other science lessons (also corroborated by other groups of students participating in the Exploratory phase). These dialogical and open stances are then not only cognitively relevant, but seem to also impact motivation and engagement, which was greatly important in a group that, according to teacher F, had behavioural and socialisation issues. It was especially interesting to see how students considered as low achievers and with a low level of prior participation in science lessons slowly started to volunteer their ideas and opinions about the topics in discussion, an indicator of an increase in their perceived self-efficacy when talking about science.

Here, as mentioned by teacher F during one of our interviews, the specific narrative-based and spiral characteristics of the TLPs seem to also have impacted students’ confidence in collaborating with the lessons. While different studies about teaching sequences and learning progressions (Leach & Scott, 2002; Duschl et al., 2011; McComas, 2014; Roblin et al., 2018) have already highlighted the importance of long-term, coherent and interconnected units of instruction for achieving specific learning goals, their impact on students’ engagement with the lessons is still underexplored, especially in the domain of NOS teaching and learning (Clough, 2018). And these effects became clear during this study: the coherence and consistency between these TLPs – informed by an overarching historical perspective about scientific development, that is, the intercultural model – offered the students similar opportunities for engagement with NOS elements throughout the whole school year, contributing to a growing familiarity with these topics.

This increasing confidence around discussions about NOS has also affected students’ knowledge about scientific work and community. Findings discussed in chapter 7 (section 7.2) showed, for instance, how the use of the spiral approach resulted in different NOS elements being explicitly explored in different discussions about NOS, with students actively employing ideas from previous lessons and TLPs to inform their arguments and suggestions in other scenarios. Nevertheless, empirical research that goes beyond the analysis of the impact of one TLP involving NOS (one topic from the science curriculum) is still scarce, and results from this investigation highlight the relevance of this spiral integration between different NOS aspects in different topics to both cognitive and enjoyment goals.

The adoption of the intercultural model of HOS to inform the construction of the historical narratives in the TLPs and the selection and connection of examples from different cultural and geographical contexts seems to have also yielded positive results in relation to which ideas about NOS were being discussed. Besides its usefulness for ‘staging the scientific story’ (Leach & Scott, 2002) – i.e. the narrative about scientific development – behind each TLP, this specific historical model promoted the integration of underexplored NOS aspects into these lessons, such as some social-institutional elements (e.g. negotiation of knowledge, exchanges, political, ethical, financial elements), as seen in the whole-class discussions, mind maps, diaries and networks in chapter 7. Consequently, this approach to NOS and to its history enabled students to have contact with examples of knowledge development from a broader and more dynamic perspective, expanding their views about who participates in scientific work, in which conditions and how this type of knowledge is negotiated and transformed. These ideas, as argued by student D in section 7.3 (“I think people forget, like, it’s not just one person, it’s a lot of people in different places working on many ideas.”), should be intrinsically part of any ‘group of NOS aspects’ found in educational proposals if we aim to help students understand science in all its robustness, diversity of contributions and complexity.

This impact of the TLPs on students’ views and talks about NOS also highlights how any scientific story portrays a specific view about scientific work. The choice of narratives and examples we make as developers of teaching resources are then not simply of instrumental nature, but they are active selections of which specific knowledge, content and voices we deem as relevant (Segall, 2004; L. Hansson, 2018), as illustrated by the specific intercultural position adopted in this investigation. What I am arguing here is that including HOS examples and narratives into science lessons is never a neutral task and should not be treated as such as in most studies in the fields of HOS, NOS and Science Education, as pointed out by Barton (2001), Erduran (2014) and Ideland (2018).

Therefore, it is important to acknowledge the part played by the field of HOS in the types of narratives and approaches to historical development of scientific ideas that are available for developers of teaching proposals. As discussed mainly throughout chapter 6, the scholarship in this area seems to be starting to engage more fully with the Global History approach, which enabled me to access relevant historical materials connected and analysed under this approach (the historical-epistemological stage). Nevertheless, most of the scientific narratives widely accessible (in the form of primary and secondary sources) in this field are still too narrow in terms of contexts, focusing on specific people, institutions or places, and paying less attention to scenarios of exchanges, collaborations, and exploitations, just like the teaching proposals they will inspire and inform. Hence, it became clear during this investigation that the kind of HOS scholarship available in the field will obviously impact the possibilities for change in the types of examples and narratives found in school science.

Lastly, as indicated by students' positive results in their end-of-year exams, another important finding from this study was the possibility of an integration between content and NOS within the time available for teacher F to explore each TLP. The use of a coherent narrative to connect concepts, ideas and tasks from different lessons in the same TLP, the dialogical approach to knowledge building throughout these lessons, and the explicit connection between NOS aspects and the development of scientific concepts can all be identified as choices at the development and teaching levels that impacted this integration between NOS and content. Therefore, although new ideas – NOS elements – were explored, instead of 'competing' for time with regular content this approach seems to have promoted a more holistic understanding of scientific knowledge, bringing together products and processes under a larger narrative.

In summary, the impact of the TLPs developed throughout this investigation on broadening in-lesson discussions and students' views about NOS and diversity in science, without any loss of regular content learning, can be linked to different decisions made at the development and teaching levels, such as:

- The question-answer approach to the promotion of explicit conversations about NOS;
- The narrative-based aspects of the TLPs;
- The spiral approach to the organisation and teaching of these TLPs;
- The use of the intercultural model of HOS (based on the Global History scholarship) to the construction of these narratives and selection of diverse examples;
- The integration between content and NOS aspects throughout all lessons and TLPs.

Nevertheless, while these choices can be related to the impact of the TLPs at the students' level, this experience cannot be understood without a closer look at another important actor involved in this process: the participant teacher. While my main goal with this project was to understand the possible effects of these TLPs on students, the role of teacher F not only at the teaching level, but also at the development level was largely relevant to the findings and ideas discussed so far. In addition, his involvement with this investigation seems to also have affected his own social, professional and personal growth (Bell & Gilbert, 2005). In the next section I will then explore teacher F's participation in this project.

8.3. Bringing the intercultural model of HOS to school science – the role of the teacher

In a recent reflection about NOS teaching and learning, Clough (2018, p. 4-5) indicated some areas that still need to be further explored by researchers in the field, including:

- How to inculcate the need for NOS in practice among teachers;
- How to prepare teachers to overcome constraints to teach NOS;
- More empirical work on implementation of NOS and on teachers' professional development.

While I do not have complete answers to these points, especially considering the small scale nature of this study, I believe that these three research topics bear a close connection with the type of work carried out during the development and implementation of the TLPs, summarised by my RQ4.1: "How can the planning and teaching of these TLPs be carried out to promote the integration of NOS into school science?" Relevant aspects of this 'planning and teaching' have already been addressed in the previous section with a focus on their impact on students, such as the intercultural model itself, and question-answer, spiral and narrative-based approaches. Nevertheless, these historical-epistemological and pedagogical choices should not be dissociated from the process involved in making and implementing these decisions in collaboration with the participant teacher.

Here I am arguing that the research topics raised by Clough (2018) are intrinsically linked to how teachers behind experiences with NOS teaching and learning actually take part in these projects. More specifically, I agree with Penuel and colleagues (2015) that teaching interventions that adopt the 'translation model'[126] (also usually called a 'top-down approach') often do not address the complexities, obstacles and possibilities arising from the work between researcher and practitioner around new

[126] "Designing and developing interventions grounded in basic research and testing interventions under real-world conditions in a wide variety of settings" (Penuel et al., 2015, p. 183).

teaching practices. In other words, while partnerships between researchers (e.g. myself) and practitioners (e.g. teacher F) are widely recognised as important for educational innovations (Guskey, 2002; Fullan, 2007; Roblin et al., 2018), accounts about these processes of collaborations and exchanges are usually absent from the literature in the NOS field [for an example see Höttecke and others (2012)], especially in relation to their complexities and transformative potential for researchers and teachers, as asked for by Clough (2018).

Interestingly, when writing and planning this investigation, I did not initially contemplate analysing the development and teaching of the TLPs from this ‘partnership’ perspective. Even though I had chosen to work with teacher F under a collaborative approach, as argued in chapters 2, 3 and 4, my original RQ about the Implementation phase focused on the students’ level, that is, on the impact of this experience on their learning about NOS, content and diversity in science. In this scenario, my partnership with the teacher was in the background of this study, acting more as a methodological choice that made sense considering my position as an outsider to the English educational system than as an analytical lens in itself.

Nevertheless, understanding this collaborative experience as part of the analysis of the Implementation phase very quickly gained importance throughout this study. From the first meeting with teacher F at the development stage the richness behind our partnership and its actual impact on building and teaching the TLPs, on students’ learning and on teacher F himself became clear, so I adopted a new analytical lens to explore this experience – ‘the role of the teacher’.

In relation to the development of the TLPs, for instance, this collaboration with teacher F aided me in the ‘translation’ of my historical-epistemological research (intercultural model of HOS) into suitable activities/tasks, narratives and pedagogical strategies. While I cannot deny a certain degree of influence of the ‘translation model’ in this work, the key aspect of this partnership was ‘mutual learning’ (Penuel et al., 2015): I was not simply translating historical knowledge to teacher F, but he was actually guiding our work throughout this translation process based on his experiences of school science and knowledge about the group of participant students.

We then consistently tried to find a middle-ground approach between ‘too tight’ (top-down) and ‘too loose’ (bottom-up) strategies for promoting an experience of educational change (Fullan, 2007) by working in a space of continuous professional exchanges between researcher and practitioner. According to Fullan (2007), innovation in teaching practices and beliefs – the ‘inculcation’ about NOS advocated by Clough (2018) – is closely linked with moments of sustained reflection and professional interactions for teachers. Throughout the Implementation phase, our pre-teaching and post-teaching meetings, along with informal chats at the end of each lesson, soon became opportunities for these professional interactions and exchanges about the TLPs, pushing both of us further in relation to the innovative ideas we had been trying to implement. As a researcher, I was constantly looking for examples, narratives and their interconnectedness to bring to our meetings. Meanwhile, teacher F was regularly having to re-think his approaches to NOS, HOS, questioning, what he valued as important outcomes from his lessons (e.g. conversations about science versus working solely on content and exam questions), and to propose ways of adapting this historical scholarship to his change environment (Clarke & Hollingsworth, 2002).

Therefore, part of my answer to Clough's (2018) call for more knowledge about how to inculcate the need for NOS in practice among teachers and how to prepare them to overcome constraints to teach NOS resides in this 'mutual learning' model of collaboration between researcher and practitioner[127], in which teachers would not simply learn more about HOS and NOS, but they would also actively re-evaluate and reflect upon their regular practice and work on the development of innovative ideas (e.g. TLPs). Nevertheless, while teachers' engagement with the production of teaching resources can positively impact educational innovation (Ball & Cohen, 1996; Leach & Scott, 2002; Bell & Gilbert, 2005; Taber, 2008), regular enactment of these materials (as opposed to stand-alone experiences) is also an important stage behind this experience.

The informal chats at the end of each lesson and the post-teaching meetings at the end of a TLP were then of great importance for the continuity of our partnership, enabling not only consistency and coherence between the different TLPs, but also flexibility for necessary changes after reflecting upon obstacles and hindrances found in the teaching of these materials. Teacher F's initial struggles with managing time around his students' constant questioning during the Medicines TLPs are an example of how enactment and subsequent reflection are relevant to a positive teaching experience from the teacher's perspective. According to Fullan (2007, p. 65), sustained reflections and professional interactions should happen both at the development stage of an innovative proposal and at experiences of enactment, involving a deep engagement in "exploring, refining, and improving". And more than simply being in accordance to the design principles adopted as a methodological strategy for this study, this 'reflection-upon-action' approach (Schön, 1991) allowed for an intensive process of mutual learning not only for me as a researcher, but also for teacher F's growth.

In their work on teachers' professional growth, Clarke and Hollingsworth (2002) argued that educational change and teachers' professional development are intrinsically linked by what they called the 'Interconnected Model of Change'. This

[127] Or 'symbiotic development' for Höttecke and colleagues (2012).

model acknowledges that change in school science practices does not only entail changes in teachers' attitudes and beliefs about an innovative proposal – the 'personal' domain (e.g. 'inculcating' them onto teaching with HOS and about NOS). It has also to be connected with professional experimentation (the domain of 'practice') to offer the teacher experiences of implementation (e.g. teaching with the TLPs), and with the reflection about which outcomes from this experience (e.g. discussions about NOS versus focusing on exam questions) are salient to his practice and aims as a science teacher (the domain of 'consequence'). Hence, similarly to Fullan's (2007) argument, these authors advocate a model of educational change that involves cyclic processes of collaborative reflection (the 'external' domain) and enactment, providing teachers with moments of practice growth ("teacher growth is constituted through the evolving practices of the teacher") and of knowledge growth (Clarke & Hollingsworth, 2002, p. 955).

Several moments of teacher's knowledge growth and practice growth were identified throughout this project. According to teacher F, at the end of this experience, he felt he had learnt "[l]oads of new content", about how to bring this new content to the curriculum, and about his own students (e.g. what kind of practices, stories and topics engage them). Overcoming his initial struggles with balancing open-ended questions, students' constant questioning and the need to move his lessons forward is an example of the teacher's ongoing practice growth throughout his work on the development, enactment and reflection upon the TLPs. A mix of spaces for knowledge and practice growth and for reflection seems to have enabled teacher F to conquer some of the constraints from his reality and to further develop his skills, while also showing him the value of bringing HOS, NOS and diverse examples to his lessons (new salient outcomes): "now I'm glad that I decided to do it, because now I can see that you can trust this process [teaching NOS], and I will do with other classes now."

At this point it is worth noticing how this narrative about teacher F's professional development can be linked to the concept of pedagogical content knowledge (PCK) – here specifically about NOS and HOS teaching. According to Shulman (1987, p. 15), PCK is "the capacity of a teacher to transform content knowledge [the historical-epistemological knowledge from the intercultural model] he or she possesses into forms that are pedagogically powerful [e.g. tasks and discussions in the TLPs]." Therefore, his growing capacity to include discussions about NOS into his lessons through in-depth planning and use of different teaching strategies, as well as through managing the debates and difficulties, can indicate an increase in his PCK about NOS and HOS teaching.

Nevertheless, I would argue that teacher's F professional development throughout this experience went beyond this specific view about the relationship between content and pedagogy entailed by the concept of PCK. Here I agree with Segall (2004) that the distinction between content (knowledge) and pedagogy (teaching strategies) seen in the PCK concept is not a clear-cut one, and that opting for the inclusion of one content, example, narrative instead of other is in itself a pedagogical strategy. This position views pedagogical strategies as more than just teaching strategies to be tried out in the lessons; they also involve the selection of specific content, of what is worth being part of the lesson.

Therefore, a more critical view of PCK would look at teacher F's professional development not simply as him working out how to introduce NOS and HOS into his lessons and 'believing in this process', but actually as him realising that NOS and HOS are integral to scientific knowledge and to the understanding of any specific school science topic. And that leaving HOS, diversity and NOS out of his lessons is a pedagogical act (Bernstein, 1996) that allows his students only a partial engagement with scientific knowledge and development ("it was a bigger topic than we planned")[128].

Still looking at teacher development, Bell and Gilbert (2005) also highlight the impact of involving teachers in the elaboration of innovative teaching resources on their personal and social development in addition to their professional growth. The personal dimension includes "managing the feelings associated with changing their activities and beliefs about science education, particularly when they go 'against the grain'" (Bell & Gilbert, 2005, p. 15), and it is usually characterised by an initial need for self-growth, going through moments of dealing with restraints (e.g. subject knowledge, behaviour control) and ending up with the teacher's empowerment in relation to the educational change being promoted.

These stages of personal growth can be seen in teacher F's experience throughout our collaboration. Interestingly, his specific beliefs about the need for diversity in science and NOS did not change during this study: he had entered this research as someone who already knew and believed in the importance of these topics to his lessons and students. Therefore, his personal development was not related to a 'change of beliefs/attitudes towards NOS', as seen in much research in this field, but actually to his desire of changing his practice around these topics, to seeking self-growth and "fulfilment as a practitioner of the art" (Clarke & Hollingsworth, 2002, p. 948).

Nevertheless, dealing with restraints arising from his change environment (e.g. control and balance of the question-answer strategy; managing to cover the TLPs in the planned timeframe) and from his perceived self-efficacy (e.g. his self-proclaimed

[128] From chapter 6: "So, I wasn't expecting it [the Evolution TLP] to be like very debate-heavy topic, but there was so much debate to keep going, keep going, keep going that it was a much bigger topic than we planned. [...] It's a much bigger topic than we give credit to be [...]."

lack of subject knowledge and confidence in teaching the Magnetism and Earth's resources TLPs) was also integral to his personal growth throughout the Implementation phase. Here it is important to highlight the impact of enacting these TLPs on teacher F's evolving perceived self-efficacy, as argued by Roblin and colleagues (2018): during our pre-teaching meetings, some of his concerns about his ability to teach topics outside his subject specialism would be touched upon[129], but in our post-teaching meetings he would then comment on how he felt comfortable and satisfied with his teaching of these TLPs[130].

This experience of engaging with the development of the TLPs in a collaborative space – where knowledge, strategies and concerns were shared and supported –, and of enacting these TLPs – where impact on students' outcomes and engagement with the lessons were actively observed and reflected upon – seems then to have taken teacher F through a process of personal growth intrinsically linked to his professional growth, impacting his perceived self-efficacy (Roblin et al., 2018). In addition, his close work in the development and teaching of the TLPs appears to have also affected his sense of 'ownership' of these resources, as illustrated by his decision to talk to other teachers at the science department in school A about this experience by sharing its positive outcomes and actively promoting the use of these TLPs[131].

Interestingly, teacher F's personal and professional growth seem to have simultaneously been influenced by and impacted his social growth (Bell & Gilbert, 2005). This specific dimension of teacher development encompasses the "development of ways of working with others that will enable the kinds of social interaction necessary for renegotiating and reconstructing what it means to be a teacher of science" (Bell & Gilbert, 2005, p. 15), and it involves a process of moving from working in isolation to valuing collaborative and then seeking/initiating collaborations.

Throughout this study, teacher F experienced a similar pattern of engagement with social growth: from his isolated routine within school A science department, he then started to see the positive effects of our collaborative work, and then to actively extend and share the TLPs and outcomes of this experience with other teachers in the department. Teacher F's specific development in the social dimension then meant that

[129] "So magnetism is such a small, kind of like a throw way topic, that I've never learned it much in-depth myself. Usually I have very little extra to add to magnetism lessons. I reckon that I'll probably learn more from this than I have to give to be honest."

[130] "I think with this one [Magnetism topic] we're going to see with their work that they'll produce next week, their assessed work, I'm heavily confident that the majority of them will do well in the magnetism section. That's based just on my feeling of the classroom you know, who is giving responses and their work."

[131] "So I shared what we've been doing, I showed them the magnetism lessons, I showed them the format of the lessons, and I showed them the actual slides. And they were really interested in this idea of stories, and context in that perspective rather than application of this context."

the TLPs, ideas and strategies we had worked on together (such as use of narratives, NOS, diverse examples, and planned questions) were now being advertised, shared and advocated to the other members of his team. Here it seems clear that this type of teacher development has a lot to contribute to future aims of scaling up these TLPs (as with any other experiences of educational innovation), which will be further discussed in the next section.

In summary and going back to Clough's (2018) call for research in the field of NOS teaching and learning, findings from this study show the promise of more collaborative approaches and development of teaching resources to teachers' professional development around NOS teaching. Furthermore, a closer look at the personal and social dimensions of teacher growth can offer insights into how more than 'inculcating the need for NOS', what it needs to be done is offering teachers opportunities for continuous processes of reflection and enactment of innovative ideas, focusing not only on innovation of knowledge (new content), but also on 'innovativeness' (capacity building) (Fullan, 2007). As argued by Fullan (2007), "ownership (...) is more of an outcome of a quality change process than it is a precondition for success."

8.4. A critique of the study

8.4.1. The Exploratory phase

In retrospect, the research strategy adopted for the Exploratory phase seems to have worked well: investigating two different settings, five science teachers and nine classes from different year groups, curriculum cycles and abilities allowed me to examine diverse practices and curricular scenarios. More specifically, the use of a case study approach to structure this phase enabled me to explore these different settings, teachers and classes (the 'cases' and 'sub-cases' under study) and their own particularities, identifying specific patterns, dissonances and links between participant students' views about HOS and NOS and their teachers' practices.

Case study methodology entails the exploration of a specific phenomenon over a long period of time (Yin, 2003), as mentioned in chapter 4. In this project, this in-depth and intensive characteristic of this methodological strategy was not only crucial to the identification of patterns and dissonances among school science practices, but also to the examination, at least partially, of the realities (contexts) behind these cases. That is, more than simply helping me to pragmatically organise and identify patterns and dissonances in the 'cases' investigated, the case study approach also allowed me to better understand the influence of contextual factors (e.g. curriculum, examinations) on these cases.

In addition, the use of a case study strategy in conjunction with a critical realist (CR) approach to my data analysis seems to have moved the description and interpretation of these cases (schools, teachers, classes) beyond a 'case-based knowledge' and towards an exploration of how they overlapped in the larger context of school science teaching and learning in comprehensive schools in England. Here, as expected and discussed in chapter 4, the multi-layered investigation of these school practices and students' ideas about HOS and NOS that was fostered by the use of a CR perspective enabled me to develop explanations encompassing both contextual and structural factors related to these cases. In this scenario, the choice of using CR and its multi-layered take on the study of social phenomena was especially useful to my understanding of the different levels of complexities, agential and structural factors impacting school science. This understanding was also relevant to the planning and development of an Implementation phase that would try to take all this complexity into account when proposing a new approach to NOS teaching.

I surely cannot assume that all interpretations, explanations and connections established between lesson observations, interviews and questionnaires are a complete representation of the cases explored throughout this phase, especially when considering that the position adopted here was one of knowledge as socially constructed. Nevertheless, the use of a CR perspective and its 'judgemental rationality' strategy offered me a pathway to strengthen my interpretations and analysis. This was mainly done not only by adopting a multi-layered perspective to the cases being investigated, as mentioned above, but also through a constant connection between my findings and explanations and other research in the field of Science Education ('theoretical redescription'). While few accounts of an empirical use of 'judgemental rationality' can be found in the current literature, I hope to have achieved here a certain degree of trustworthiness in my answers to RQs 1, 2 and 3.

Despite these positive experiences with the use of case studies and CR as methodological approaches, some limitations can be identified mainly in relation to the sampling process and size, and methods of data generation. It can be said that investigating schools and teachers that were interested from the beginning in the topics of my investigation (i.e. NOS, HOS and diversity in science) could limit the practices and scenarios I would be able to observe and the responses to interviews and questionnaires I would be able to gather. Interestingly though was the fact that even if these participant teachers had initially highlighted their concerns about these topics, the enactment of these ideas in their lessons was varied within the group, providing me with a richness of observations and examples of practices. Hence, while the sample type could be an initial obstacle to the generation of meaningful findings for other scenarios (e.g. teachers and schools that are not interested in NOS, HOS or diversity in science), this wide range of different approaches to science lessons helped me to identify relevant patterns (e.g. focus on exam results and conceptual learning) and mechanisms (e.g. time and curricular constraints, teaching materials available) operating behind these realities.

This identification of patterns and mechanisms then helped me to also overcome, to some extent, the limitations of my small sample size. My in-depth and year-long work at schools A and B meant that a large amount of varied types of data (observations, interviews, and questionnaires) was generated about these two research sites, and the challenge was then to recognize overarching themes to describe similar phenomena that were happening in both settings, and to establish connections between these themes (arising from the practice) and teachers' and students' views about NOS, HOS and diversity in school science.

In addition, while this use of different methods of data generation did not always lead to triangulation of the findings in a strict sense (i.e. looking at the same research question in three distinct ways), interconnecting observations, interviews with teachers and students and questionnaires certainly helped me to cross-check my own interpretations with the different participants and to explore more nuanced ideas and explanations related to the initial data generated about these teachers' and students' realities. Here, the inspiration from CR that was behind my analysis of these data was useful to the construction of these connections and multi-layered takes on the cases under study: exploring the different dimensions that were influencing what was actually being observed in the lessons, questionnaires and interviews under a multi-layered perspective allowed me to understand these findings within the larger system of science education in England.

Still about these methods of data generation, I need to acknowledge that they are not perfect and, as such, they could not have possibly conveyed all the views and practices linked to my research topics. With the observations, more topics could have been investigated, especially those initially deemed by the teachers as not including NOS aspects, to explore similarities and differences between their practices in two scenarios perceived by them as diverse. Obstacles related to being a sole researcher carrying out all the data generation in this study prevented me from doing so. Furthermore, my active presence in their lessons might have influenced how teachers were teaching: by knowing I was interested in NOS, HOS and diversity, they might have changed their approach to address my research aims. To partially overcome this hindrance, I opted to observe them teaching different topics throughout a whole school year, which seems to have 'diluted' this possible initial willingness to please me in their everyday routines.

Interviews had also their negative side, especially with students: they can seem artificial when compared to their original routines and they placed students in a position where they had to talk to an external member to the school community about their teachers' practices. My choice of only interviewing the participant students at the end of that school year helped me to partially overcome this obstacle, since by then their familiarity with me was at its peak (aided by my constant work assisting them and their teachers in their lessons).

In relation to the HOS and NOS questionnaires, while the choice of using open-ended instruments appears to have paid off in terms of richness of data, some questions (e.g. remembering names of scientists or classifying questions are scientific or not) only acquired more explanatory meaning when discussed during the interviews, allowing me to further establish connections between answers to questionnaires, reasons for them and experiences of school science. This highlights, as discussed in chapter 4, the importance of pairing up questionnaires and follow-up interviews when exploring students' ideas about HOS and NOS, an approach that helped me to partially overcome some limitations of these two instruments, such as the lack of a validation step with a large sample of students.

On the positive side, these instruments were useful in generating initial answers and ideas to be explored in these interviews. In the case of the HOS questionnaire, there are very few similar instruments available in the literature (Gurgel et al., 2014) and, while this one has its own limitations (e.g. remembering names of scientists), its value to the exploration of what students actually know about scientists' and communities' contributions to science and its history became clear over the course of this investigation.

Similarly, the NOS questionnaire offered some interesting insights into students' views about NOS. More important though was the method chosen to organise and analyse students' answers to this instrument: Epistemic Network Analysis (ENA). As with most open-coding processes, the large amount of data generated through this questionnaire posed a challenge to this study and ENA has shown itself as a powerful method for schematising data about 'ideas'. The visualisation of students' views about NOS in the form of networks not only offered me a way to organise and quantify the incidence of the several codes produced during the analytical process, but also moved this analysis beyond the quantification of isolated ideas. Through this method, views about NOS were not simply identified, but the connections among them and how they had been linked in different ways to make sense of scientific work actually became the most important feature of the findings generated through this instrument. Personally, I believe this to be a refreshing and promising method of questionnaire analysis that can bring useful insights to different research in the field of Education.

8.4.2. The Implementation phase

The main methodological choices employed throughout the Implementation phase are similar to those adopted during the Exploratory phase (e.g. case study and CR strategies, HOS and NOS questionnaires, follow-up interviews), thus the main reflections explored in the previous subsection also apply here. Nevertheless, some particularities of this second research stage need to be further analysed.

In the case of the lesson observations during the Implementation phase, my presence in the lessons might have influenced how the teacher worked with the TLPs, but our close collaboration throughout and his active participation and growing familiarity with the goals behind these resources seem to have been more important to his decisions and to how he led these lessons. An interesting follow-up from this study could look at how teacher F is currently teaching these TLPs to his new year 8 groups after working on these materials for the first time, and how this is happening without my presence in these lessons. The time frame involved in writing up this thesis and the individual nature of this study did not allow for this type of investigation though.

On a different note, as with any small-scale project, questions about scalability will arise when considering my work with teacher F. While the development of the Exploratory phase in two different schools, involving five science teachers and 200 students aimed at offering some more general insights into NOS, HOS and diversity in school science, I cannot ignore the fact that the TLPs were created and implemented in a very specific context, with one science teacher and one year 8 group of students. In this scenario, some final thoughts on how to possibly scale up this experience are necessary.

Roblin and colleagues (2018) commented on the lack of studies in the field of Science Education around the scalability of specific curricular innovations, a scenario that can be partially associated with difficulties in following up from one-off individual experiences like the one described in this doctoral study. Nevertheless, some indirect indicators of potential for scalability can be identified even scenarios like mine, such as sustainability and spread (Roblin et al., 2018).

In relation to the sustainability of this experience – which involves “maintaining these consequential changes over substantial periods of time” (Clarke & Dede, 2009, p. 354) –, observing teacher F working with the TLPs in the new school year was not possible due the time and personal constraints behind this study, as discussed above. Nevertheless, we kept constant communication after the end of this project, and his initial comments were that the TLPs were still going well and that he was still comfortable with these resources. While these results are only anecdotal at best, they are an indication of the sustainability of this experience, which can be attributed, at least partially, to his professional and personal growth during our work on the TLPs, involving changes in knowledge, practice and ownership of these materials.

As already explored in the previous section, teacher F's active work in sharing and advocating the use of these TLPs to other science teachers at school A is a sign of a 'spreading process' occurring at the local level (other teachers and classes at the same school). Whilst this strategy (teacher-teacher sharing) is helpful for scaling up innovative proposals, it is important to remember that educational change is multidimensional and involves more than just sharing new teaching resources (Fullan, 2007). Enactment and feedback in a collaborative environment are also relevant dimensions for scaling up innovations, especially if we consider that other teachers at school A might have different starting points from teacher F regarding their knowledge about NOS/HOS, and question-answer, narrative-based and spiral approaches.

Since these teachers are not benefiting from the same collaborative and feedback-based environment as originally experienced by teacher F, it is difficult to predict how the spread of the TLPs will happen. In this scenario, however, possibilities of teacher F himself acting as an initial mentor for his colleagues should also be considered. As argued by Fullan (2007), teacher-to-teacher links in everyday school life can greatly impact educational change by creating a professional learning community within the school that can go on without an outsider researcher. Unfortunately, time and personal constraints rendered it impossible for me to follow-up this 'spreading process' and teacher F's participation, but I agree here with Roblin and others (2018) that relevant insights for material development can arise from this type of study.

The same can be said about scaling up these TLPs to different schools and even to other curricular contexts. According to Clarke and Dede (2009, p. 353) "adapting a locally successful innovation to a wide variety of settings – while maintaining its effectiveness [...] – is very challenging". Different change environments will mean that teaching resources need to balance main goals with space for flexibility/adaptability. While this expansion to different contexts was not investigated in this study, possible ways of carrying out this process were explored during my final interview with teacher F:

> Teacher: "I think [to scale this up] **it should be integrated into existing schemes of work**, because the resources are so good that they allow the teacher to kind of pick it up and play, just go with it. **With the slides and tasks coming with loads of comments about them, it's the best pick up and play scheme of work that I've used in years.**"

> Researcher: “OK. But if we have different types of teachers, what do you think it needs to be done for these resources to be flexible enough?”
>
> Teacher F: “This is really hard to be done, because all these different types of teachers. What it could be done is to **create lessons with like five key elements**. So something like a talk element, a quiz element, a demonstration element, a cognitive elements (like the learning goals), and a consolidation element as well. Right? And the idea is then that **if you need a resource for lesson, you can go to the scheme of work and have a language and a layout of lesson which is very easy for you to adapt and change to your style**. [...] So taken these styles of resources and **putting them into the language and style [of a specific school community] would be easier enough for adaptation and for sharing with other teachers**.”

Teacher F highlights the importance of written support embedded in the resources, of a common language and a layout for these resources (coherence), and of adapting them to the specific style of the school community where they will be applied as factors influencing the process of scaling up this experience. Interestingly, he also mentions adaptation from a school community/sharing perspective and not simply from a specific teacher’s standpoint. This hints to his view about the relevance of a collaborative and sharing environment – the ‘school community’ – for the spreading of these resources, also illustrated by his talk about how these TLPs should be included in the schemes of work in other schools.

Lastly, some limitations of the TLPs themselves should be touched upon here. That was the case, for instance, of the question-answer strategy adopted to address NOS elements more explicitly in the lessons. Teacher F’s initial struggles with balancing dialogic and authoritative approaches to the discussions and historical narratives indicate the high level of skill required for an effective work with this type of narrative-based TLPs, as also mentioned by Leach and Scott (2002) in their work with science teaching sequences. Furthermore, while teacher F’s ability to manage these question-answer moments seems to have grown throughout this experience, most of the interactions found in these lessons were still initiated by him (teacher’s initiation), with less discussions actively started by his students. This raises questions about the types of pedagogical strategies usually adopted by proposals based on HOS, like the one developed throughout this project. Hence, future research might benefit from exploring different teaching and learning strategies that are still based on historical narratives but that also promote more students’ initiations and peer collaboration (e.g. inquiry tasks), while also taking into consideration the level of professional skills required from teachers to work with these resources.

In addition, the development of these TLPs, while based on findings from the Exploratory phase about students’ interests in NOS and HOS, did not take into consideration what they generally expect from their science lessons. This resulted in an overall enjoyment of this experience and a feeling of “good learning” at the end of it mixed with complaints about the lack of experiments and of written notes to guide them through their revisions. Results from their end-of-year exam showed that this participant group had performed well when compared to other year 8 groups at school A, but their concerns regarding their learning prior to the exam were real – even if contrasting with their feeling of “good learning” from the TLPs – and they could have been taken into account from the beginning by this project. Future research in the development of HOS and NOS teaching materials might then be interested in exploring more this interplay between collaborative work with participant teachers and inputs from the students also involved in the process.

8.5. Contributions and implications of the study for future research

Throughout this thesis I have been arguing about the importance of teaching and learning about NOS and about the necessity of changing school science practices and teaching resources addressing this topic. And I hope the findings presented and analysis developed in my empirical chapters have provided some insights into the possibilities from HOS and NOS to science teachers’ everyday practices and students’ engagement with school science. Nevertheless, beyond these ‘contributions to practice’ – that is, beyond suggestions built and implemented here in the form of the TLPs – what can be said about the implications of this study for research in Science Education and for the field of HOS?

First, I believe there is an important learning from this project that could be relevant to the field of HOS. While historians of science (e.g. Collins & Shapin, 1989; Cooter & Pumfrey, 1994; Matthews, 1995; Miller, 2001) have for decades advocated the relevance of their work to increasing ‘public understanding of science’, the field seems to have done little to develop actual strategies for engaging with other related fields, such as Science Education, Policy and Communication (Holton, 2003; Chang, 2017). For instance, in a recent review, Orthia (2016) argued that HOS research and changes in approaches and frameworks within the field (e.g. feminist and decolonial studies) are rarely transferred from this discipline to other related domains (she mentions as examples the fields of Science Education and Science Policy). In a reflection paper, Chang (2017) attributes this situation to a disconnection between the work of historians of science (in the form of academic research) and what he calls ‘Applied History of Science’ (how this research is communicated to other related fields).

Throughout my Exploratory and Implementation phases, I investigated not only which images students had of science, but also to what extent those views were related to school science realities and whether these realities were also connected with the engagement of science educators with historical scholarship. While one finding from the Exploratory phase around HOS was clearly linked to Orthia's (2016) and Chang's (2017) evaluation of the field – a discontinuity between recent historical scholarship and approaches to HOS in schools –, the experience of introducing the intercultural model of HOS into regular science lessons during the Implementation phase offered some insights into how this engagement of HOS with other fields can be done: through a more 'horizontal', collaborative approach.

More than 15 years ago, Holton (2003) was already calling attention to the disconnection between 'History of Science' and 'Applied History of Science' mentioned above. According to the author, some barriers to this work are professional differences (e.g. "professional preparation, preoccupation, reward systems, journals, professional societies") and the lack of "organizational support or cross-cultural competence for reaching out across the divide" in the academia (Holton, 2003, p. 603). While he highlighted the importance of cooperative approaches to bridge this divide, his concrete suggestions were still mainly linked to 'translation' strategies (Penuel et al., 2015), that is, to the publication of curriculum materials, papers and activities that would 'advertise' HOS to and be 'consumed' by, for instance, science educators. In other words, while the relevance of HOS to other related fields is acknowledged, very few approaches look at this interaction beyond 'top-down' strategies (such as the 'Perspectives on Science' project[132]).

During my work with a new type of historical scholarship (Global HOS), it became clear that simply adopting a position of 'translator' of these academic publications into 'teachable resources' would not be enough to ease the conversation between the Science Education and HOS fields. As argued throughout this chapter, the specific approach to HOS that has been for decades embedded in curricular materials, school's practices and in the public images of scientific work cannot be transformed into something different simply by 'top down' initiatives of science communication strategies (Gregory & Miller, 1998; Miller, 2001; Collins & Pinch, 2005). On the contrary, an important learning from this study for the field of HOS is that collaborative approaches to HOS communication seem to be more effective in promoting the spread of new historical scholarship to other fields than the sole production of HOS pieces.

Interestingly, while this effectiveness of collaborative experiences between practitioners and academic researchers is well-known and established in the Education

[132]htps://www.pearsonschoolsandfecolleges.co.uk/FEAndVocational/Science/ALevelPhysics/PerspectivesonScience/Samples/SampleMaterial/Perspectives_on_Science_Sample_Pages.pdf

field, those involved with HOS studies seem to still favour the 'top-down'/'translation' model (e.g. Holton, 2003). Thus, I hope lessons from this research can offer encouragement to historians of science to pursue this kind of collaboration to address their concerns with how their work is communicated to others ('Applied History of Science'), and insights into how these partnerships can be carried out from the perspectives of these other professionals (such as teacher F). Summarising my small contribution to the field here, I suggest that a possible 'model' for this collaboration should involve, but not exclusively:

- Historians of science learning more about the contexts in which their academic work has the potential to 'applied' (e.g. science departments in primary and secondary schools; policy offices and agencies) to better understand their realities (e.g. curriculum development, school routine, teachers' interests) and how historical scholarship can be beneficial there;
- The active pursuit of partnerships with other professionals in these settings (e.g. heads of science departments, science teachers, curriculum developers, policy makers) – that would involve historians of science not simply being accessible as 'sources of historical knowledge' for these professionals (e.g. teaching a course on HOS for trainee teachers), but to be available for long-term collaborations around the development of different ideas and strategies of science communication that are relevant to specific contexts, realities, interests and needs.

This experience with the introduction of a new type of historical scholarship into school science also resulted in some relevant 'lessons' for the field of Science Education, mainly in relation to the debates about Multicultural Science Education (MSE) and Nature of Science (NOS) introduced in chapter 2. Much has been discussed in the past two decades about whether and how to address questions of diversity and multiculturalism in school science practices and contexts that are still mainly concerned with exams, accountability, and learning of specific lists of content, and different positions have been advocated within the field of Science Education. While philosophical discussions between 'universalists' and 'relativists' about what counts as 'science' (and, thus, about what should be part of science lessons) are important, very little has been done in the field to move this debate forward and generate ideas for re-thinking science curricula and schemes of work. That is the case, for instance, of research developed with specific minority groups in Western countries (e.g. Jegede & Aikenhead, 1999; Barton et al., 2008; Hernandez et al., 2013). Nevertheless, could we re-think science curricula and schemes of work under this multicultural perspective for all students, from all backgrounds, like the participants in this research?

Throughout this thesis I argued that insights from the field of Global HOS can be of great value to this re-thinking about how the gap between MSE and the teaching and learning of regular science content can be bridged. My work here was mainly on the conceptualisation of an intercultural model of HOS and on how it could be used to inform the development of teaching resources and the organisation and connections between different TLPs. Thus, I believe that an important contribution from this project to the field of Science Education was the generation of a possible model to ground the integration and accommodation of different concerns and debates around MSE.

Obviously, I do not presume to have solved all the philosophical and social justice issues arising from these discussions, but I believe to have contributed to the field by offering a possible pathway through this debate in the form of an intercultural model of HOS inspired by innovative perspectives coming from the HOS scholarship. Future research in the field of Science Education might then be interested in investigating the usefulness of this model to different curricular contexts, school's realities, science topics, and to the organisation of complete schemes of work and curriculum design.

In addition, results from teacher F's engagement with this study – such as his knowledge growth, self-efficacy beliefs, and spiral teaching with HOS – could be further explored in teacher development programmes to better understand the affordances of this intercultural model to teachers' knowledge and practice growth in relation to MSE and HOS. Also, the adoption of a more horizontal, collaborative approach to my work with teacher F seems to be a promising 'model' for promoting this knowledge and practice growth and the introduction of innovative strategies around MSE, HOS and NOS into school science, as opposed to solely top-down, large-scale, one-size-fits-all reforms.

Another fundamental learning from this project is related to NOS research: the intercultural model of HOS was useful not only for promoting diversity in school science talks, but also for broadening and integrating teaching and learning of scientific content and its nature. That is, while questions of social justice arising from MSE debates are hugely relevant, my point here is that looking at scientific development from a more intercultural viewpoint can also impact content and NOS teaching.

As recently argued by some researchers in this field (Erduran, 2014; Aragón-Méndez, Acevedo-Díaz & García-Carmona, 2018; Ideland, 2018), a reconceptualisation of NOS is important if we aim at broadening and diversifying people's images of science, which would involve a move from the sole focus on traditional epistemic aspects (e.g. theories, models, experimentation) to a deeper and more critical work with social-institutional aspects and their interplay with epistemic ones. In this specific research scenario, the proposed intercultural approach to HOS offered possibilities for the construction and implementation of narratives about scientific development that address this broader and more critical model of NOS for Science Education.

In other words, due to its holistic and critical viewpoint about science, I believe this intercultural model of HOS could help expand these debates about NOS, while also acting as an overarching framework to inform long-term, coherent and interconnected strategies for innovative curricula development. More specifically, our experience with this model during this project highlighted the importance of a balance between localised examples of scientific work and the exploration of their interconnections (a global perspective) to a better and deeper understanding of the social-institutional aspects operating within scientific development. In addition, the use of an overarching framework such as the intercultural model to inform the organisation of examples and discussions about NOS within and between different TLPs also seems a promising strategy to be further explored by new research in a field that is still very much dedicated to the construction and implementation of stand-alone, disconnected teaching proposals.

In summary, I believe that the most original contributions of this investigation to knowledge as well as research in the field of (Science) Education can be outlined as:

- A conceptualisation of an <u>intercultural model of HOS</u> to facilitate the inclusion of discussions about cultural and historical diversity in scientific development into school science, addressing some of the debates around MSE that have arisen in the past decades without losing sight of scientific content from regular curricula. Consequently, an <u>expansion of NOS teaching and learning</u> beyond more traditional proposals found in the field by re-balancing the exploration of epistemic and social-institutional aspects of scientific development, while also delving deeper into less explored NOS aspects, such as science's political, financial, environmental and intercultural roots.

- In an attempt to expand and diversify research methods for investigating views about NOS, the use of <u>Epistemic Network Analysis (ENA)</u> to facilitate both the visualisation of large datasets of answers to open-ended questionnaires, and the connection between different ideas about NOS when thinking about specific cases of scientific development. ENA offered me a second level of analysis around students' views about NOS, since it led not only to the practical organisation of different statements employed by the participants to answer the NOS questionnaire, but also to the unveiling of interesting connections between these statements which often remain hidden when using common tables or charts to display this kind of data.

- Still in relation to research methodologies, the use of a critical realist (CR) stance to the design of this study, which involved not only adopting a multi-method strategy to data generation, but more importantly a multi-layered approach to the organisation, analysis and further interpretation of these data, including the establishment of links between agential, structural and locally-specific findings. In addition, in this investigation I employed the theoretical concept of 'judgemental rationality' to inform the approach to data validity and reliability throughout my analysis, one the very few empirical accounts of the use of this strategy (beyond theoretical exercises) available in the field of Education.

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APPENDICES

Appendix 1: Preliminary interviews with science teachers (summer/2016)

Interview schedule

Question 1.

a) Can you tell me what you think the aims of school science are? Or to put it another way, what would you like your students to gain from learning science in your classes?

b) How do the aims of science as a subject differ from other school subjects?

c) How does school science differ from science itself?

Question 2.

a) What do you consider to be a good science lesson?

taking into account the answer to the previous question...

b) What kind of approach do you like to use in your science lessons? (e.g. practical work, lectures, group or individual work, games, debates, pen-and-pencil work, etc.)

Question 3.

a) How long have you been teaching science?

taking into account the answer to the previous question...

b) Do you see any difference in science teaching since you have started as a teacher (or since you were a student in secondary school)?

taking into account the answer to the previous question...

c) Do you think your students have changed since then? If so, how?

taking into account the answer to the previous question...

d) What would you say the most important obstacles to students' science learning are nowadays?

e) What have been the main influences on you as a teacher over the last couple of years? (e.g. practical, theoretical, personal, professional development, etc.).

Reflective notes about these preliminary interviews

When analysing the interviews with science teachers at school A, I identified some commonalities among their discourses, mainly due to the influence of a departmental approach towards science teaching and their long tradition as a science-specialised school. Here, different topics were explored through these interviews to bring to light their views about science teaching, and common discourses permeated mainly three interconnected themes: aims of school science, careers aspirations, and in-lesson motivation.

In general, these teachers pointed out motivating students towards science as one of the main goals of school science, especially in KS3 and KS4. This motivational feature is not only related to career aspirations (that is, motivating students to continue their studies in science) but also to day-to-day engagement and learning (that is, coming to the lesson with a real interest in the topic being taught). Nevertheless, while some teachers, like Teacher2 and Teacher4 (resonating their positions as leaders of KS4 and KS5 curricula, respectively) placed more emphasis on directing students to scientific careers, others like Teacher1 and Teacher3 were more concerned with a general motivation towards learning science (or 'science for all'). The choice of activities and approaches is very broad, but most of them argued that taking students' own interests and realities (the 'everyday science') into account is a preferred pathway to engaging them.

In this context, their opinions about the aims of school science seem to resonate with their own practices as teachers, where their decisions about what (content) and how (pedagogy) to teach is usually related to the type of students they have in their classes. It is interesting to see their division between low and high ability groups when talking about their lesson planning, where top set students receive a broader science teaching (with more space to debates, out-of-school and up-to-date knowledge, and an in-depth diversion from the regular curriculum), whereas students from the bottom sets are usually more bounded to the curriculum and exams (according to Teacher5, these students only want to learn what they need for their exams and nothing more).

Even though teachers' discourses are generally very similar, some particularities were identified. This is the case, for instance, of teaching about NOS (or 'how science works'), a theme that was brought up during the interview only by some teachers. Mainly Teacher1 and Teacher4 highlighted learning about the scientific world and 'how science works' as one of their goals when teaching science (though they argued that this is more feasible with high ability students). Teacher1, in particular, was very interested in my research and he dedicated a big part of the interview to his views about teaching about NOS and bringing different approaches to his lessons.

Other teachers like Teacher2, Teacher3 and Teacher5, on the other hand, placed more emphasis on doing hands-on activities and practicals as one of their main goals when developing their lessons, mainly due to motivational and careers aspirations (Teacher2, for instance, believed that the very nature of science is based on inquiry). I am not arguing here that teaching about NOS has nothing to do with hands-on activities and scientific inquiry, but those teachers with a wider view of what 'learning about how science works' (or NOS) could be more interesting to work with when taking into account my research aims.

Similarly, both Teacher1 and Teacher4, maybe because they are also pedagogy leaders at this school, specifically criticized the indiscriminate use of inquiry and practicals in KS3 and KS4 as only a tool for motivation, without further concerns about what students are learning. Both advocated the use of these (and other types of) activities as tools to engage and to encourage students' critical and inquisitive learning.

Additionally, Teacher3 also seemed to be an interesting participant to work with, mainly due to her concerns about 'science for all', about bringing everyday knowledge to science lessons, and her willingness to develop and adapt different lesson plans and approaches. During my preliminary observation sessions at school A, I noticed her creativity and openness when delivering her lessons and, in her interview, she also highlighted this interest in helping students to develop an in-depth knowledge about science, especially in top set classes.

Appendix 2: Demographic questions from the HOS questionnaire

This survey asks questions about you, your family and some things you know about science. This is NOT A TEST; I just want to know what you think. There are no right or wrong answers. I WILL NOT SHARE YOUR ANSWERS, FAMILY AND PERSONAL INFORMATION WITH ANYONE, INCLUDING YOUR TEACHERS. I just need this information to better understand your classroom, your history and what you know about science, and I'll connect all this information with the observations I've been doing of your science lessons.

Part I – About you and your family

1. Please, enter the name of your school:

____

2. Please, enter your full name:

____

3. Which year group are you in?

☐ Year 8 ☐ Year 9 ☐ Year 10

4. Are you a girl or a boy?

☐ Girl ☐ Boy

5. Which of the following best describes you? (Please choose only ONE, more options will follow)

☐ Asian (Jump to question 5.1.) ☐ Middle Eastern (Jump to question 5.5.)

☐ Black (Jump to question 5.2.) ☐ White (Jump to question 5.6.)

☐ Chinese or East Asian (Jump to question 5.3.)

☐ Mixed and Multiple ethnic groups (Jump to question 5.4.)

☐ Other (Please, specify:_________________)

5.1. You chose Asian, which of the following best describes you?

☐ Indian ☐ Pakistani ☐ Bangladeshi

☐ Other Asian (Please, specify:____________________)

5.2. You chose Black, which of the following best describes you?

☐ Caribbean ☐ African

☐ Other Black (Please, specify:____________________)

5.3. You chose Chinese or East Asian, which of the following best describes you?

☐ Chinese ☐ Japanese ☐ Korean

☐ Other East Asian (Please, specify:_____________________)

5.4. You chose Mixed and Multiple ethnic groups, which of the following best describes you?

☐ Asian and Black ☐ Black and White

☐ Asian and White

☐ Other Mixed and Multiple ethnic group (Please, specify:______________________________)

5.5. You chose Middle Eastern, which of the following best describes you?

☐ Arabic ☐ Jewish

☐ Kurdish

☐ Persian ☐ Turkish

☐ Other Middle Eastern (Please, specify:______________________)

5.6. You chose White, which of the following best describes you?

☐ British (English, Scottish, Welsh, and/or Northern Irish)

☐ Irish ☐ East European

☐ Other Continental European (Please, specify:___________________)

☐ Other White non-European (Please, specify:____________________)

6. Which of the following best describes your religious beliefs? (Please choose only ONE)

☐ Buddhist ☐ Hindu

☐ Muslim ☐ Christian ☐ Jewish

☐ Sikh ☐ No religion

☐ Other religion (Please, specify: _________________)

7. Is English your first language? ☐ Yes ☐ No

If no, which language do you and your family speak at home most of the time? _________________

8. Were you born in the UK? ☐ Yes ☐ No

If no, where were you born? ____

9. Was your mother born in the UK? ☐ Yes ☐ No

If no, where was she born? ____

10. Was your father born in the UK? ☐ Yes ☐ No

If no, where was he born? ____

Appendix 3: Demographic information about the participant students – Exploratory phase

Table I. Participant students in the Exploratory phase

School	Classes		# students	Gender	Ethnicity	Total
	Year	Ability group[133]				
A	8	Mixed	23	Female = 52 Male = 83	Asian = 40 White East European = 38 Black African = 18 Middle Eastern = 12 Mixed = 11 White British = 7 Black Caribbean = 4 East Asian = 2 White African = 1 Chinese = 1 Other = 1	135
	9	Set 1	26			
		Set 2	24			
		Set 3	16			
	10	Set 1	25			
		Set 2	21			
B	8	Set 2	25	Female = 65 Male = 0	Black African = 29 Black Caribbean = 11 Mixed = 6 Asian = 6 White East European = 5 Middle Eastern = 3 White British = 3 East Asian = 1 Other = 1	65
	9	Set 3	17			
	10	Set 1	23			
Total	9		200	Female = 117 Male = 83	Black African = 47 Asian = 46 White East European = 43 Mixed = 17 Black Caribbean = 15 Middle Eastern = 15 White British = 10 East Asian = 3 White African = 1 Chinese = 1 Other = 2	200

133 Ability groups (sets 1, 2 and 3 – from higher to lower) are classrooms where students with similar abilities (as assessed by their schools) are placed together, in opposition to mixed groups, where students have different abilities.

Appendix 4: Demographic information about the participant teachers – Exploratory phase

Table II. Participant teachers

School	Teacher[134]	Gender	Ethnicity	Years of teaching	Subject
A	B	Male	Asian	10	Chemistry
	F	Male	White British	8	Biology and Physics
	P	Female	Asian	15	Chemistry
B	A	Female	Black African	8	Chemistry
	K	Female	Black Caribbean	15	Biology

[134] Teachers' names have been changed for anonymity reasons.

Appendix 5: Lessons observed during the Exploratory phase

Table III. Summary of classes and lessons observed during the Exploratory phase

School	Year	Class	Ability group	Teacher	Subject	Topics
A	8	8Y	Mixed	F	Science	- Drugs and Alcohol - Inheritance (genetics) - Space - Magnetism
	9	9A1	Set 1	F	Biology	- Microscope - Animal and plant cells - Stem cells
				B	Chemistry	- Endo/exothermic reactions
		9A2	Set 2	F	Biology	- Microscope - Animal and plant cells - Stem cells
		9A3	Set 3	B	Chemistry	- Electrolysis - Endo/exothermic reactions
	10	10B1	Set 1	P	Chemistry	- Earth's atmosphere - Earth’s resources
		10B2	Set 2	P	Chemistry	
B	8	8Y2	Set 2	A	Science	- Magnetism - Inheritance and natural selection
	9	9X3	Set 3	K	Science	- Universe - Radioactivity - Turning points in Chemistry
	10	10X1	Set 1	K	Biology	- Stem cells

Appendix 6: Follow-up interviews schedule – Participant teachers – Exploratory phase

About the observations...

1. I want to start by talking about the examples (items, cases) you use during your lessons to introduce/discuss a specific topic. How do you choose these examples you're going to present to your students? (present examples from my observations).

2. Still about that, one of the findings from my observations is that usually teachers don't spend a lot of time having in-depth discussions about these examples; that is, they usually move very quickly throughout the examples during the lessons (present findings from my observations). What do you think of that? Is that usually a reality for you?

- If YES, why do you think that happens? Is it a personal choice (a personal view on what science teaching should be about) or are there other factors influencing your approach?
- If NO, how do you plan your lessons to ensure you'll have these discussions with your students?

3. Do you think this lack of in-depth discussions about the examples can influence students' views about how the scientific community works, such as how scientists work and who they are?

- Do you think learning about these things is relevant to your students? Why? (present findings about types of NOS and implicit versus explicit approaches)
- For you, what are the most important things for students to learn in your lessons (e.g. content, applications of science, how science works, etc.)?

4. Still talking about this idea of how science works, do you think that some specific topics in the science curriculum are more open to this type of discussion than others? Could you give some examples from your own experience? (present examples from my observations).

5. Do you think there's any difference to teaching about how science works in relation to sets and/or age groups (KS3 and KS4)? Could you give examples from your own experience? (present examples from my observations).

6. Another overall finding from my research is that teachers usually make a lot of connections between the topic they're teaching, other subjects, students' previous knowledge or personal interests, everyday life, etc. That means that these science lessons are usually very open for students' questions and that teachers are always asking their students questions as well (present findings from my observations). How important is this for your practice? Why?

• What you do say about making connections between the topic and other cultures (including your students' own backgrounds) or historical contexts? Is that relevant for your practice? Do you take this idea into account when thinking about your lesson? (present examples from my observations).

About the questionnaires...

7. One of the questionnaires I applied to your students was connected to their knowledge about scientists and different countries' contributions to science. As an overall finding, there seems to be a large disconnection between remembering the names of scientists and actually remembering the work they've done and their origins (present my findings about scientists). Why do you think that happens?

• One of my hypotheses for this scenario is that just briefly mentioning the names of scientists and their work (an illustrative approach) quickly during the science lessons might not be enough for students to internalise this knowledge. In this case, as a science teacher, I keep thinking that we're just giving them a check list of names to remember, without any actual learning about these people and their work. What do you think about that?

8. Do you think the introduction of these discussions about scientists and their work (that is, History of Science) is relevant to your students? Why? If YES, what do you feel the main obstacles for doing that are?

9. Another finding from this questionnaire is the lack of diversity in students' knowledge about scientists and countries in science, both in terms of the scientists they cited (gender, race, ethnicity) and the countries they considered as relevant to science in the past and nowadays (present my findings about scientists and countries). Why do you think that happens? (my hypothesis: lack of diversity in the examples employed by the teachers during their lessons and effects of curricular constraints/decontextualised approaches)

10. Do you think we have a problem with representation of scientists and cultures in school science? Why? If YES, what do you think the main impact of this scenario on students is?

• Thinking again on my previous question about using examples from different cultures in your lessons, do you feel able to address this while planning and teaching your lessons (curriculum/time constraints, lack of materials, etc.)? Why/How?

• At the end of the interview, present the preliminary results from the NOS questionnaire (overall findings) as an illustration of students' main views about science/NOS.

Appendix 7: Demographic information about the students in the focus groups – Exploratory phase

Table IV. Demographic information from the participant students in the focus groups during the Exploratory phase

School	Year	Ability group (%)[1]		Gender (%)[2]		Ethnicity (%)	
		Whole class	Focus group	Whole class	Focus group	Whole class	Focus group
A	8	L=25 M=50 H=25	L=40 M=40 H=20	F=48 M=52	F=60 M=40	White East European=57 Middle Eastern=26 Asian=9 Black African=4 Mixed=4	White East European=40 Middle Eastern=20 Asian=20 Mixed=20
	9	H=100	H=100	F=42 M=58	F=40 M=60	Asian=46 White British=15 White East European=11 Black African=8 Black Caribbean=4 Mixed=4 Chinese=4 East Asian=4 Middle Eastern=4	Asian=20 White British=40 White East European=20 Chinese=20
		M=100	M=100	F=54 M=46	F=60 M=40	Asian=29 White East European=25 Black African=22 Black Caribbean=8 Mixed=8 White British=8	Asian=40 White East European=20 Black African=20 White British=20
		L=100	L=100	F=12 M=88	F=50 M=50	White East European=31 Black African=19 Mixed=19 Asian=19 White British=6 White African=6	White East European=25 Mixed=25 Asian=25 White African=25

Table IV. Demographic information from the participant students in the focus groups during the Exploratory phase (cont.)

School	Year	Ability group (%)[1]		Gender (%)[2]		Ethnicity (%)	
		Whole class	Focus group	Whole class	Focus group	Whole class	Focus group
A	10	H=100	H=100	F=44 M=56	F=50 M=50	White East European=32 Asian=28 Middle Eastern=16 Black African=12 Mixed=4 Black Caribbean=4 East Asian=4	White East European=50 Asian=25 Middle Eastern=25
		M=100	M=100	F=19 M=81	F=40 M=60	Asian=43 Black African=19 Mixed=14 White East European=14 Middle Eastern=5 Other=5	Asian=40 Black African=20 White East European=20 Middle Eastern=20
B	8	M=100	M=100	F=100 M=0	F=100 M=0	Black African=52 Black Caribbean=16 White British=8 White East European=8 Asian=8 Mixed=4 Other=4	Black African=40 White British=20 Mixed=20 Other=20
	9	L=100	L=100	F=100 M=0	F=100 M=0	Black African=41 Black Caribbean=29 Mixed=18 Middle Eastern=6 White British=6	Black African=41 Black Caribbean=29 Mixed=18 Middle Eastern=6 White British=6
	10	H=100	H=100	F=100 M=0	F=100 M=0	Black African=39 Asian=17 White East European=13 Middle Eastern=9 Black Caribbean=9 Mixed=9 East Asian=4	Black African=50 Middle Eastern=16.7 Black Caribbean=16.7 East Asian=16.7

[1] L = low ability group; M = medium ability group; H = high ability group
[2] F = female; M = male

Appendix 8: Follow-up interviews schedule – Focus groups with students – Exploratory phase

1. I want to start by talking about the first questionnaire you helped me with, that one about names of scientists and countries that are important to science. A lot of students mentioned Albert Einstein and Stephen Hawking. Have you ever heard about them?
- If YES, can you tell me where you heard about them and what you know about them?
- If NO/YES, can you tell me where you heard about the scientists you named for me?

2. In that questionnaire, I also asked you if you remembered where these scientists came from and what they did in science. However, most students only remembered the names and nothing about where these scientists were born and what they did (present some examples from their answers). Why do you think that happened?

3. Does your science teacher talk about scientists during her lesson?
- If YES, what do you think about that? Do you like it? Why?
- If NO/YES, would you like to know more about scientists in your lessons? Why? And what would you like to know?

4. Let's talk about these scientists. Almost all scientists the students cited are men, white and European or from the USA (present some examples from their answers). Why do you think this list of scientists is like that?
- Do you know any scientists (famous or from your family/friends) from other backgrounds, like women, black and from different parts of the world?
- In your opinion, which type of person becomes a scientist? Who do you have to be to become a scientist?
- Do you think the lack of diversity in science can influence people's choice of career? What about yours?

5. Let's talk about countries in science. The most cited countries were USA, UK and China (present some examples from their answers). Why do you think this list of countries is like that?
- In which type of places (countries, communities) do you think science is usually developed?
- Talk to them about examples of science being done in different parts of the world at different times (e.g. metal technology in Africa; Arabic astronomy; Indian maths; Chinese inventions; Medicine in the native Americas), and ask if they would like to learn more about it.

6. Let's talk now about the other questionnaire you helped me with, that one about how science works. Can we talk about what science does? What do you think a scientist's job is?

7. Most of you talked about the importance of having evidence to science. What do you think evidence is? Can you give me examples?
- How do you think scientists gather this evidence?
- And what about the situations where gathering evidence is very difficult (like in the dinosaurs' case or when they research outer space)? How you think scientists work in these situations?

8. Do you think gathering evidence is the only important part of scientific work? That is, is this enough for developing scientific ideas?
- What else do you think is important in this task?

9. Can we talk now about how scientists and the general public receive new scientific ideas? Do you think people nowadays trust scientists and their work? Why?
- Can this situation occur between scientists? Do you think scientists can distrust each other? Why do you think that happens?
- Do you think social contexts (e.g. politics, economy, culture, etc.) can affect the way scientists work? Why? How?

10. Lastly, I want to talk about where all these ideas about how science works came from? Where did you learn/hear about that (school, family/friends, media, etc.)?

Appendix 9: NOS questionnaire – Complete version

This survey asks questions related to what you know about science and how science works. This is NOT a test; I just want to see what you know about this topic. I will not share your answers with your teachers.

Please, enter the name of your school: ____

Please, enter your full name: ____

Which year group are you in?

☐ Year 8 ☐ Year 9 ☐ Year 10

Are you a girl or a boy?

☐ Girl ☐ Boy

1. Read the following questions and decide if they are scientific questions or not scientific questions (use a cross X to mark your answer on the table). Please, give your reasons in a few words for each of your choices.

Question	Scientific	Not scientific	Not sure	Give your reasons
Which is the best programme on TV?				
Is it wrong to keep dolphins in captivity?				
What diet is best to keep babies healthy?				
Is it cheaper to buy a large or a small packet of washing powder?				
How was the Earth made?				
Is the Earth's atmosphere heating up?				

2. Galileo Galilei (1564-1642) was a famous scientist who lived in Italy, at a time when most leading thinkers followed Aristotle's (a Greek philosopher) ideas. At that time, people believed that the Earth was at the centre of the universe (geocentric model) and that the surfaces of the moon and the planets were smooth, uniform and perfectly spherical. Galileo wanted to see whether these ideas were right. In 1609, he constructed his own "home-made" telescope (one of the few telescopes in the world at that time) and pointed it towards the sky. He found out that the surface of the moon was uneven, rough, and full of cavities and bumps, chains of mountains and deep valleys. He also found objects in orbit around Jupiter and not around the Earth, concluding that the Earth was not the centre of everything in the universe. He quickly published his findings, but his ideas were not easily accepted and he suffered a lot of opposition.


Image source: National Geographic

a) Galileo faced a lot of opposition from other scientists and the general public to his theories. Why do you think that happened?

b) After some decades, Galileo's theories started to be accepted by other scientists. In your opinion, why did these other scientists start to accept his theories?

c) Do you think that oppositions to <u>new scientific theories</u> still exist <u>today</u>? Why might new scientific ideas be opposed nowadays?

d) Can you give examples of situations or cases where present-day scientists faced (or could face) oppositions to their work?

3. Scientists agree that about 65 millions of years ago the dinosaurs became extinct, but they disagree about what caused this to happen.

The first theory, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction.

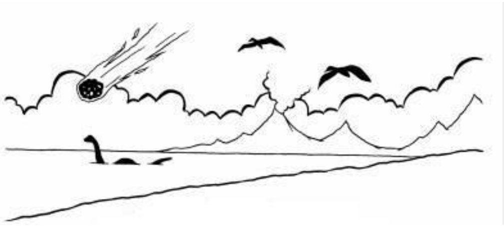
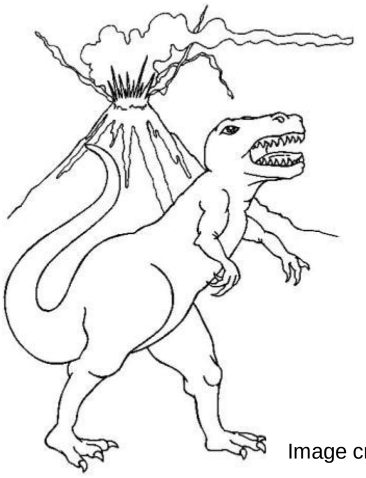


Image source: https://www.freepik.com



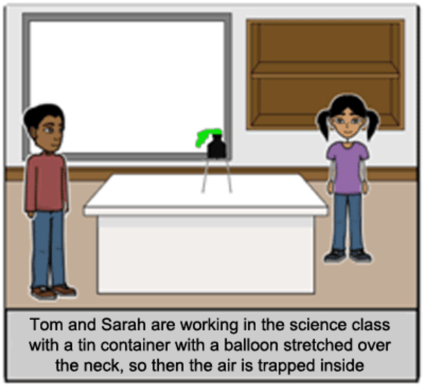
The second theory, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction.

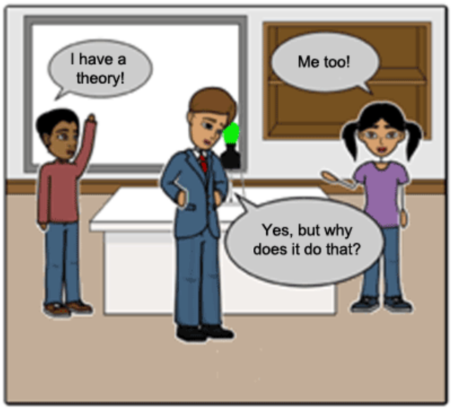
Image credit: Albert David Sutton

a) Why do you think they disagree even though they all have access to similar scientific information?

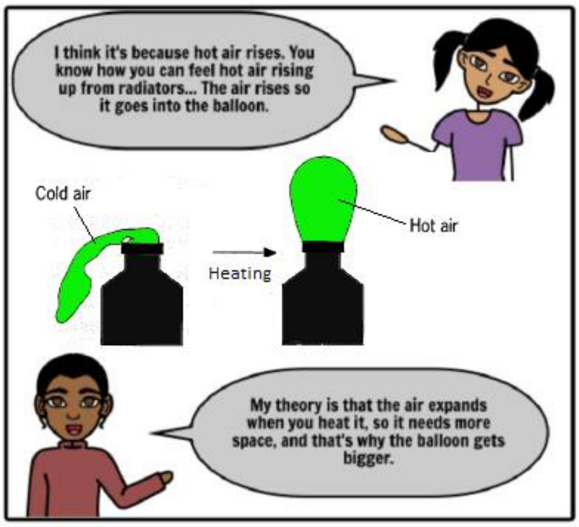
b) If a scientist wants to persuade other scientists of their theory for dinosaur extinction, what do you think they have to do to convince the others? Explain your answer.

4. Read the following cartoons and answer the questions when they appear:



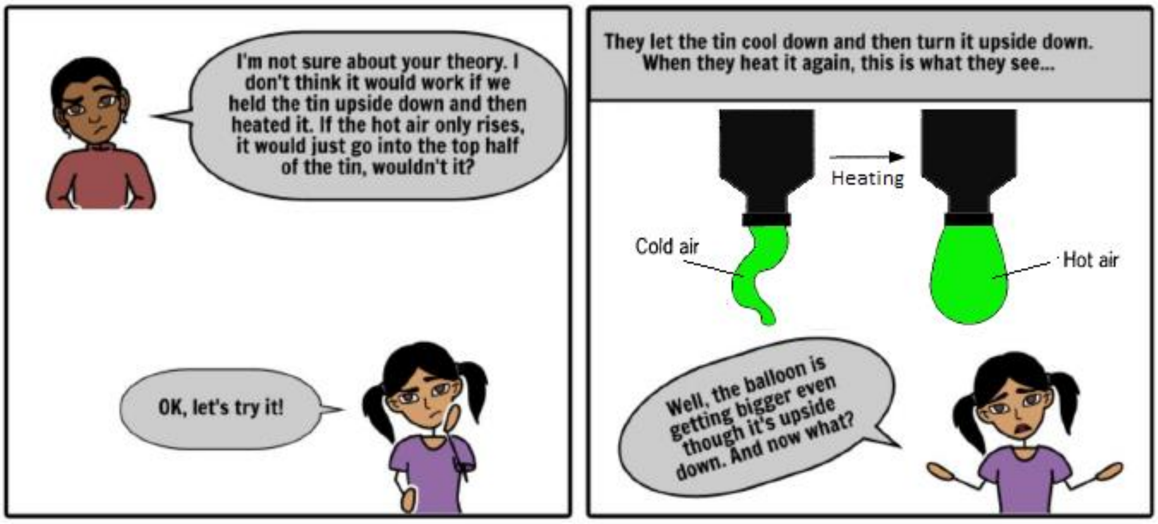


a) What does “theory” mean in science?



b) How did Tom and Sarah come up with their theories?

c) What could they do to check if their theories are good ones?



d) Does this prove that Sarah's theory had a problem? Why?

e) Which of these theories (Tom’s or Sarah’s) is best at explaining what happened in both experiments? Why?

5. a) In your opinion, what are the main objectives of scientific work/science?

b) Could you give some examples of things or activities where science is involved <u>outside the school</u>?

6. The model of the inside of the Earth shows that the Earth is made up of layers called: crust, mantle, outer core and inner core.

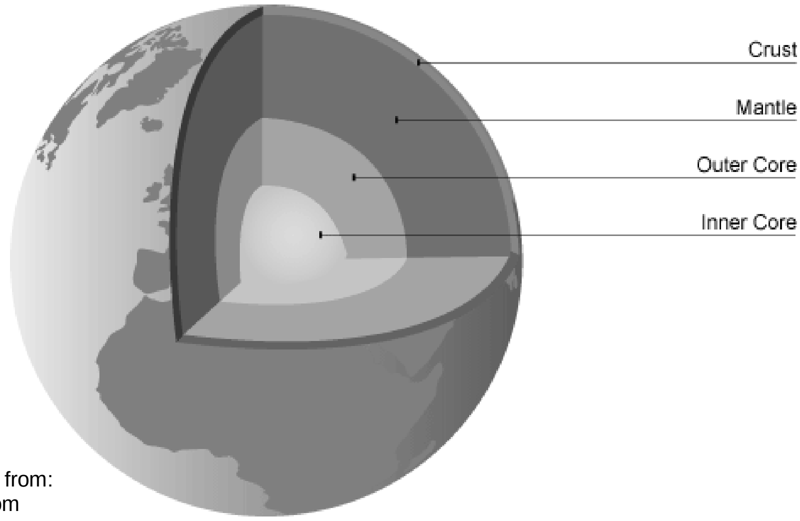


Image adapted from: https://www.freepik.com

a) What do you think a “scientific model” is?

b) Does the model of the layers of the Earth show exactly what the inside of the Earth looks like? Why?

c) Knowing that it is very difficult to observe the inside of the Earth, how do you think scientists created this model? Which kind of investigation do you think they used?

Thank you very much for your help! ☺

Appendix 10: NOS questionnaire – Coding system – Exploratory phase

Table V. Coding system for the NOS questionnaire – Exploratory phase

Question 1		
#	**Final code/statement**	**Description**
1	Science involves investigating and expanding knowledge about people and the world	Answers related to 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, etc.
2	Science is not interested in political, economical or subjective values	Answers stating that science is not interested in financial/economics/political/ethical/moral stances, personal opinions, preferences, choices, beliefs, etc.
3	Science develops useful knowledge/things for everyday life, society and environment	Answers related to the usefulness of science. Answers that state that science can produce/create knowledge and/or technology/appliances that can inform/aid everyday life tasks/choices/routines/life quality, society in general and/or environmental scenarios (including solving problems).
4	Science is a subject matter/domain specific	Answers that associate science to specific subjects (e.g. Chemistry, Physics, Biology, etc.) and also disassociate it from others (e.g. Maths, Geography, History, etc.). Also, answers that associate science to specific topics/domains, such as "brain", "health", "universe" (e.g. "it's scientific because it is about health") and disassociate it from other topics/domains, such as TV programmes (e.g. "it's not a scientific question because TV has nothing to do with science"). Here, answers are connected to a view of science as a subject bounded to specific areas of interest (usually related to school science subjects).
5	Science can involve statistical/pattern studies	More specific answers stating that science can be involved in studies about behaviour, preferences, etc. because these studies can involve statistical methods and analysis of patterns.
6	Science is about facts/right answers	Answers that are more specific related to science being interested in finding facts about things and/or fixed/right answers about specific questions and/or proving people wrong (e.g. "it's not scientific because is about choice and not facts").
7	Science is not related to everyday activities/ technology	Answers where the student clearly that there is no relationship between science and everyday life activities or technology/appliances.
8	Science involves testing, finding evidence and/or making predictions	Answers that specifically state that scientific work is related to experimental tasks/scientific methods, such as carrying out tests, experiments, trials, finding evidence/data/facts, making observations and making predictions from data. It has a more experimental component in comparison to code #1.

Table V. Coding system for the NOS questionnaire – Exploratory phase (cont.)

Question 2		
#	**Final code/statement**	**Description**
9	Scientists can resist new or different scientific ideas	Answers stating that scientists can resist new and/or opposite/different ideas/theories, especially if they follow another school of thought (e.g. “Galileo faced a lot of opposition to his theories because people followed Aristotle’s ideas and thought that it was true”).
10	Instruments and technology impact scientific discoveries/ideas	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, etc (e.g. “Galileo had scientific evidence due to the fact he had a telescope”).
11	There can be different explanations, disagreement and competition among scientists	Answers stating that it’s common for scientists to have different explanations/theories/ideas about the same phenomena/event (disagreements are part of life) and that scientists can distrust other scientists’ work (e.g. “they didn’t know if Galileo’s evidences were correct”). In some cases, answers are also related to scientists being jealous of each other, wanting to be always right, to be the first to discover something or to become famous.
12	A theory/model has to be strongly connected to empirical evidence/experiments to be accepted	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, etc. (e.g. “they didn’t believe Galileo because he didn’t have any evidence for his theory”).
13	Science can conflict with people's worldviews or political stances	Answers stating that people can resist new scientific ideas but specifically because these ideas can conflict with their personal/religious/cultural/political beliefs/worldviews. It’s a more specific case of code #9, involving more personal stances than general scientific philosophies/ideas (e.g. some students citing Donald Trump’s approach towards some scientific matters as an example).
14	Disagreement between scientists can occur because science is still in development	Answers stating that it’s common for scientists to disagree specifically because we don’t know everything about science/world yet, so many things are still to be studied and debated among them (e.g. “challenges and oppositions to new scientific theories still exist today because lots of pieces of the world have not been scientifically discovered”).
15	Scientists have authority and power over knowledge about the world	Answers stating that people believe/agree with something said by scientists because they are scientists and they know what they are doing, because they are right (e.g. “they started believing in Galileo because he was right”).
16	Scientific theories have to be well explained/founded	Answers stating that scientific theories/ideas have to be well explained, it has to “make sense”, must be detailed or “more scientific”. There’s a component here strongly connected to the power of the scientific rhetoric and to how scientists communicate their ideas to others, how they make themselves understood (e.g. “Tom’s theory is better because he went into more detail”).
17	Scientific theories are rarely opposed nowadays	Answers stating that nowadays scientific theories/ideas rarely face oppositions.
18	Science involves resilience and hard work	Answers stating that scientists work hard to develop their theories and carry out investigations (e.g. “people started to believe Galileo because he worked hard to prove he was right”).

Table V. Coding system for the NOS questionnaire – Exploratory phase (cont.)

Question 2		
#	**Final code/statement**	**Description**
19	Scientific ideas are shared/investigated/debated by a community of people	Answers stating that scientific theories/ideas can be collective investigated by different scientists, that they can share their findings/results and debate their ideas to get them right, to advance their knowledge/comprehension about a topic.
23	It's important for scientific theories to be repeatable and generalisable	Answers stating that a theory must be repeatable (that is, it works every time it's applied to a phenomena/event) and generalisable (that is, it can be applied to other cases/scenarios and still explain them well) to be accepted by others.
29	A scientific theory can be proved right or wrong	Answers clearly stating that scientific theories can be proved right/wrong in a later stage of research, with more evidence/studies, etc (e.g. "they started believing him because his theories were proved right").
37	People can distrust/resist new ideas	Answers stating that the general public can resist new ideas (e.g: "people were against the idea of something new")
Question 3		
#	**Final code/statement**	**Description**
9	Scientists can resist new or different scientific ideas	Answers stating that scientists can resist new and/or opposite/different ideas/theories, especially if they follow another school of thought (e.g. "Scientists disagree about the dinosaurs because they believe in different things").
10	Instruments and technology impact scientific discoveries/ideas	Answers stating that having access to instruments and other forms of technology can help new discoveries, gathering new data/evidence, developing new ideas/theories, etc (e.g. "They disagree because they researched it using different equipments").
11	There can be different explanations, disagreement and competition among scientists	Answers stating that it's common for scientists to have different explanations/theories/ideas about the same phenomena/event (disagreements are part of life) and also that scientists can distrust other scientists' work. In some cases, answers are also related to scientists being jealous of each other, wanting to be always right, to be the first to discover something or to become famous (e.g. "they disagree because they are jealous of each other" or "they disagree because they want to become famous first").
12	A theory/model has to be strongly connected to empirical evidence/experiments to be accepted	Answers stating, in different ways, that scientific ideas/theories/models are based on and must explain empirical evidence/data/findings/observations/results from experiments, etc. (e.g. "they disagree because they don't have evidence to prove their point" or "to convince the others, they should get evidence to prove their theory").
16	Scientific theories have to be well explained/founded	Answers stating that scientific theories/ideas must be well explained, it has to "make sense", must be detailed or "more scientific". There's a component here strongly connected to the power of the scientific rhetoric and to how scientists communicate their ideas to others, how they make themselves understood (e.g. "Tom's theory is better because he went into more detail").

Table V. Coding system for the NOS questionnaire – Exploratory phase (cont.)

Question 3		
#	**Final code/statement**	**Description**
18	Science involves resilience and hard work	Answers stating that scientists work hard to develop their theories and carry out investigations.
19	Scientific ideas are shared/investigated/debated by a community of people	Answers stating that scientific theories/ideas can be collective investigated by different scientists, that they can share their findings/results and debate their ideas to get them right, to advance their knowledge/comprehension about a topic.
20	It can be difficult to gather evidence to prove a scientific idea	Answers stating that there are some cases where it can be difficult to have access to the evidence needed to inform a theory/idea and that maybe that could be the explanation for scientists' disagreement about something (e.g. "they disagree because it was such a long time ago, it is hard to find proof of what happened").
21	Scientific theories can be based on different types of evidence and interpretation	Answers stating that scientists may have conflicting ideas/disagreement because they were using different types of evidence to inform their research or because they were interpreting the same evidence in different ways.
22	Scientific theories and models can be informed by previous knowledge/research on the topic	Answers stating that people/scientists can employ their previous knowledge/research about the topic to come up with their theories/models.
23	It's important for scientific theories to be repeatable and generalisable	Answers stating that a theory must be repeatable (that is, it works every time it's applied to a phenomena/event) and generalisable (that is, it can be applied to other cases/scenarios and still explain them well). E.g: "to convince the others they have to show that their theory works with evidence gathered from other places around the world".
24	Models can help to partially represent/explain a scientific idea or physical structure	Answers stating that scientists can use models to explain their ideas/theories about a phenomena/event.
25	Scientists and their work can be influenced by socio-historical contexts or personal opinions	Answers stating that maybe we can have different theories about a phenomenon because they were developed in different social, political, historical, economical contexts and by different people, with different opinions on the topic (e.g. "maybe they disagree because their theories were developed in different historical moments").
26	Scientific theories are unproven ideas	Answers stating that scientific theories are ideas about a phenomenon that haven't been proved yet (e.g. "they disagree because these are just theories, they are not proved").
29	A scientific theory can be proved right or wrong	Answers clearly stating that scientific theories can be proved right/wrong. It can be a complement to code #26, when the student not only states that it's an unproven idea, but also that it could be proved in later stage, with more evidence/research, etc (e.g. "they have to prove the other theory wrong").

Table V. Coding system for the NOS questionnaire – Exploratory phase (cont.)

Question 4		
#	**Final code/statement**	**Description**
12	A theory/model has to be strongly connected to empirical evidence/experiments to be accepted	Answers stating, in different ways, that scientific ideas/theories/models are based on and must explain empirical evidence/data/findings/observations/results from experiments, etc. (e.g. "they came up with their theories by doing experiments").
16	Scientific theories have to be well explained/founded	Answers stating that scientific theories/ideas must be well explained, it has to "make sense", must be detailed or "more scientific". There's a component here strongly connected to the power of the scientific rhetoric and to how scientists communicate their ideas to others, how they make themselves understood (e.g. "Tom's theory is better because he went into more detail").
19	Scientific ideas are shared/investigated/debated by a community of people	Answers stating that scientific theories/ideas can be collective investigated by different scientists, that they can share their findings/results and debate their ideas to get them right, to advance their knowledge/comprehension about a topic (e.g. "they could ask their teacher or other students to check their theories").
22	Scientific theories and models can be informed by previous knowledge/research on the topic	Answers stating that people/scientists can employ their previous knowledge/research about the topic to come up with their theories/models (e.g. "they came up with their theories using their prior knowledge").
23	It's important for scientific theories to be repeatable and generalisable	Answers stating that a theory must be repeatable (that is, it works every time it's applied to a phenomena/event) and generalisable (that is, it can be applied to other cases/scenarios and still explain them well). E.g: "Tom's theory is better because it works for both experiments".
25	Scientists and their work can be influenced by socio-historical contexts or personal opinions	Answers stating that maybe we can have different theories about a phenomenon because they were developed in different social, political, historical, economical contexts and by different people, with different opinions on the topic (e.g. "scientific theories are their opinions on the topic").
26	Scientific theories are unproven ideas	Answers stating that scientific theories are ideas about a phenomenon that haven't been proved yet (e.g. "theory is an idea that was not proved yet").
27	A scientific theory is an idea, a prediction or a hypothesis about something scientific	Answers solely stating that theories are ideas, hypothesis or prediction about something.
28	A scientific theory is an explanation for events/phenomena	Answers stating that theories are explanations/ reasons for how/why something (event/phenomenon) works (e.g. "theory means that they have an idea or story behind why this happened").
29	A scientific theory can be proved right or wrong	Answers clearly stating that scientific theories can be proved right/wrong. It can be a complement to code #26, when the student not only states that it's an unproven idea, but also that it could be proved in later stage, with more evidence/research, etc (e.g. "theory is an idea that has yet to be proved right").
30	A scientific theory cannot be proved right or wrong	Answers clearly stating that scientific theories cannot be proved right/wrong. It can be a complement to code #26, when the student not only states that it's an unproven idea, but also that it could never be proved right in later stage, with more evidence/research, etc (e.g. "theory is an idea that cannot be proved").

Table V. Coding system for the NOS questionnaire – Exploratory phase (cont.)

Question 5		
#	**Final code/statement**	**Description**
1	Science involves investigating and expanding knowledge about people and the world	Answers related to 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, etc.
3	Science develops useful knowledge/things for everyday life, society and environment	Answers related to the usefulness of science. Answers that state that science can produce/create knowledge and/or technology/appliances that can inform/aid everyday life tasks/choices/routines/life quality, society in general and/or environmental scenarios (including solving problems).
4	Science is a subject matter/domain specific	Answers that associate science to specific subjects (e.g. Chemistry, Physics, Biology, etc.) and disassociate it from others (e.g. Maths, Geography, History, etc.). Also, answers that associate science to specific topics/domains, such as "brain", "health", "universe" (e.g. "it's scientific because is about health") and disassociate it from other topics/domains, such as TV programmes (e.g. "it's not a scientific question because TV has nothing to do with science"). Here, answers are connected to a view of science as a subject bounded to specific areas of interest (usually related to school science subjects).
6	Science is about facts/right answers	Answers that are more specific related to science being interested in finding facts about things and/or fixed/right answers about specific questions and/or proving people wrong (e.g. "it's not scientific because is about choice and not facts").
7	Science is not related to everyday activities/technology	Answers where the student clearly that there is no relationship between science and everyday life activities or technology/appliances.
8	Science involves testing, finding evidence and/or making predictions	Answers that specifically state that scientific work is related to experimental tasks/scientific methods, such as carrying out tests, experiments, trials, finding evidence/data/facts, making observations and making predictions from data. It has a more experimental component in comparison to code #1.
18	Science involves resilience and hard work	Answers stating that scientists work hard to develop their theories and carry out investigations (e.g. "people started to believe Galileo because he worked hard to prove he was right").
19	Scientific ideas are shared/investigated/debated by a community of people	Answers stating that scientific theories/ideas can be collective investigated by different scientists, that they can share their findings/results and debate their ideas to get them right, to advance their knowledge/comprehension about a topic (e.g. "they could ask their teacher or other students to check their theories").
31	Science is part of workplaces, informal spaces and media	Answers stating that there is science involved with specific jobs (such as doctors, pharmacists, engineers) and workplaces (such as industries, power plants, etc.), as well as that science can be found in informal spaces and in the media (such as museums, TV shows, books, etc).
32	Science is a lucrative business	Answers stating that one specific goal of scientific work is to generate money, to work as any other business.

Table V. Coding system for the NOS questionnaire – Exploratory phase (cont.)

Question 6		
#	**Final code/statement**	**Description**
10	Instruments and technology impact scientific discoveries/ideas	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, etc (e.g. “They can use equipments to develop this model of the Earth”).
12	A theory/model has to be strongly connected to empirical evidence/experiments to be accepted	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, etc.
15	Scientists have authority and power over knowledge about the world	Answers stating that people believe/agree with something said by scientists because they are scientists and they know what they are doing, because they are right (e.g. “a scientific model is model that was approved by scientists”).
22	Scientific theories and models can be informed by previous knowledge/research on the topic	Answers stating that people/scientists can employ their previous knowledge/research about the topic to come up with their theories/models.
24	Models can help to partially represent/explain a scientific idea or physical structure	Answers stating that scientists can use models to explain their ideas/theories about a phenomena/event.
33	Models are based on indirect evidence and/or estimations	Answers stating that models are developed using evidence/data gathered through indirect methods (such as scanning, fossils, rocks, etc.) and/or estimations.
34	Models are based on direct evidence/testing	Answers stating that models are developed using evidence/data gathered through direct methods (such as digging roles, sending people to the inside of the Earth, etc.).
35	Models are 100% accurate representations/explanations of a scientific idea or physical structure	Answers stating that scientific models are 100% accurate, that is, that they represent exactly what the phenomenon is/how it works.
36	Models are diagrams or images of something scientific	Answers stating that models are images/pictures/diagrams/physical representations of something scientific, usually (but not always) citing the difference in scale.

Appendix 11: Demographic information about the participant students – Implementation phase

Table VI. Participant students in the Implementation phase

<table>
<tr><th rowspan="2">School</th><th colspan="2">Class</th><th rowspan="2"># students</th><th rowspan="2">Gender</th><th rowspan="2">Ethnicity</th></tr>
<tr><th>Year</th><th>Ability group</th></tr>
<tr><td>A</td><td>8</td><td>Mixed</td><td>26</td><td>Female = 11
Male = 15</td><td>Asian = 12
Black African = 5
White East European = 3
White others = 2
Mixed = 2
Middle Eastern = 2</td></tr>
</table>

Appendix 12: Students' impressions of the Implementation phase - questions from the HOS questionnaire ('post-implementation')

1. You are finishing another year of science lessons at the school and we would like to know your opinion about teacher F's lessons about these topics: Medicines, Magnetism, Evolution, and Earth's resources:

a) What did you like the most about these lessons? Why?
b) What did you like the least about these lessons? Why?
c) Do you see any difference between these specific science lessons and your science lessons with other teachers this year and in year 7? Please explain.
d) During these lessons, what are the main things you learnt about how the scientific community and scientists work?
e) Among these 4 topics (Medicines, Magnetism, Evolution, and Earth's resources), which one do you think you learnt most about? Why?
f) Among these 4 topics (Medicines, Magnetism, Evolution, and Earth's resources), which one do you think you learnt least about? Why?

Appendix 13: Follow-up interviews schedule – Focus groups with students – Implementation phase (‘post-implementation’)

1. I want to start by talking about your science lessons with teacher F about Medicines, Magnetism, Evolution and Earth’s resources.

a. What did you like the most? Why? (probe them in relation to the Q&A/whole class discussions, examples used, type of questions asked, etc.)
b. What did you like the least? Why?

2. Lots of the questions you discussed with teacher F during these science lessons were related to ‘how science and scientists work’.

a. Do you remember examples of questions that made you think about how science works during these lessons?
b. Were they different from other questions in the science lessons? How?
c. Did you like talking about how science works? Why?
d. What do you think you learned about how science works during this year? Probe them to think about the aspects below using the lessons Medicines, Magnetism, Evolution and Earth’s resources as examples:

- Importance of natural resources to science and technology;
- Collaborative, creative and tentative nature of scientific work;
- Science, ethics, economy, politics, environment;
- Relationship (and differences) between science and technology;
- Controversies and disagreements in science;
- Relationship between evidence, explanation and theory;
- Scientific and non-scientific explanations and questions;
- Models and experiments in science.

3. Last year you answered a questionnaire about scientists and places where science is done and was done in the past. Most of your answers were related to white, European male scientists and countries.

a. Do you think your lessons with teacher F showed you something different about where scientific knowledge can come from? Why? And what? (probe them to think about examples from the lessons)
b. Did you like to learn more about these different people and places related to scientific development? Why?
c. If you learned about these different people and places in the lessons, why you did not talk about them in your questionnaire?

Appendix 14: Follow-up interviews schedule – Focus groups with students – Implementation phase ('pre-implementation')

1. I want to start by talking about the questionnaire about names of scientists and countries that are important to science. A lot of students mentioned Albert Einstein and Stephen Hawking. Have you ever heard about them?
• If YES, can you tell me where you heard about them and what you know about them?
• If NO/YES, can you tell me where you heard about the scientists you named for me?

2. In that questionnaire, I also asked you if you remembered where these scientists came from and what they did in science. However, most students only remembered the names and nothing about where these scientists were born and what they did. Why do you think that happened?

3. Do your science teachers talk about scientists during their lesson?
• If YES, what do you think about that? Do you like it? Why?
• If NO/YES, would you like to know more about scientists in your lessons? Why? And what would you like to know?

4. Let's talk about these scientists. Almost all scientists the students cited are men, white and European (or from the USA). Why do you think this list of scientists is like that?
• Do you know any scientists (famous or from your family/friends) from other backgrounds, like women, black and from different parts of the world?
• In your opinion, which type of person becomes a scientist? Who do you have to be to become a scientist?
• Do you think the lack of diversity in science can influence people's choice of career?

5. Let's talk about countries in science. The most cited countries were US and UK. Why do you think this list of countries is like that?
• In which type of places (countries, communities) do you think science is usually developed?

6. Let's talk about how science works. Can you read the following questions in the cards (give them individual cards) and decide if they are scientific questions or not scientific questions? Why?

- Which kind of fabric is waterproof?
- Can any metal be made into a magnet?
- Do ghosts haunt old houses at night?
- Which is the best football team?

(probe them further by asking about what characterises a 'scientific question' and 'scientific work')

7. Now let's talk about some examples of scientific research. Can you take a look at this story about Alfred Wegener and his work on Continental drift? (show them the video summarising the case[135]).

• Thinking about Wegener's story, what do scientists usually mean by the words 'theory' and 'evidence'?
• Was having evidence (for instance, plants, rock and fossils from different continents) enough for Wegener's idea to be accepted? Why?
• What else is important for developing new scientific ideas?
• Why do you think he faced a lot of oppositions from other scientists?
• Do you think this still happens nowadays?
• What do you think scientists do to convince others about their ideas?

[135] Edited version of the following video: https://www.youtube.com/watch?v=nbU809Cyrao&t=1s

8. Can we talk now about how scientists and the general public receive new scientific ideas? Do you think people nowadays trust scientists and their work? Why?

- Can this situation occur between scientists? Do you think scientists can distrust each other? Why do you think that happens?
- Do you think social contexts (e.g. politics, economy, culture, etc.) can affect the way scientists work? Why? How?

9. Lastly, I want to talk about where all these ideas about how science works came from? Where did you learn/hear about that (school, family/friends, media, etc.)?

Appendix 15: NOS questionnaire – Coding system – Implementation phase

Table VII. Coding system for the NOS questionnaire – Implementation phase

Question 1		
#	**Final code/statement**	**Description**
1	Science involves investigating and expanding knowledge about people and the world	Answers related to 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, etc.
2	Science is not interested in political, economical or subjective values	Answers stating that science is not interested in financial/economics/political/ethical/moral stances, personal opinions, preferences, choices, beliefs, etc.
3	Science develops useful knowledge/things for everyday life, society and environment	Answers related to the usefulness of science. Answers that state that science can produce/create knowledge and/or technology/appliances that can inform/aid everyday life tasks/choices/routines/life quality, society in general and/or environmental scenarios (including solving problems).
4	Science is a subject matter/domain specific	Answers that associate science to specific subjects (e.g. Chemistry, Physics, Biology, etc.) and disassociate it from others (e.g. Maths, Geography, History, etc.). Also, answers that associate science to specific topics/domains, such as “brain”, “health”, “universe” (e.g. “it’s scientific because it is about health”) and disassociate it from other topics/domains, such as TV programmes (e.g. “it’s not a scientific question because TV has nothing to do with science”). Here, answers are connected to a view of science as a subject bounded to specific areas of interest (usually related to school science subjects).
6	Science is about facts/right answers	Answers that are more specific related to science being interested in finding facts about things and/or fixed/right answers about specific questions and/or proving people wrong (e.g. “it’s not scientific because is about choice and not facts”).
8	Science involves testing, finding evidence and/or making predictions	Answers that specifically state that scientific work is related to experimental tasks/scientific methods, such as carrying out tests, experiments, trials, finding evidence/data/facts, making observations and making predictions from data. It has a more experimental component in comparison to code #1.
19	Scientific ideas are shared/investigated/debated by a community of people	Answers stating that scientific theories/ideas can be collective investigated by different scientists, that they can share their findings/results and debate their ideas to get them right, to advance their knowledge/comprehension about a topic.

Table VII. Coding system for the NOS questionnaire – Implementation phase (cont.)

Question 2		
#	**Final code/statement**	**Description**
9	Scientists can resist new or different scientific ideas	Answers stating that scientists can resist new and/or opposite/different ideas/theories, especially if they follow another school of thought (e.g. "Galileo faced a lot of opposition to his theories because people followed Aristotle's ideas and thought that it was true").
10	Instruments and technology impact scientific discoveries/ideas	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, etc (e.g. "Galileo had scientific evidence due to the fact he had a telescope").
11	There can be different explanations, disagreement and competition among scientists	Answers stating that it's common for scientists to have different explanations/theories/ideas about the same phenomena/event (disagreements are part of life) and that scientists can distrust other scientists' work (e.g. "they didn't know if Galileo's evidences were correct"). In some cases, answers are also related to scientists being jealous of each other, wanting to be always right, to be the first to discover something or to become famous.
12	A theory/model has to be strongly connected to empirical evidence/experiments to be accepted	Answers stating, in different ways, that scientific ideas/theories/models are based on and must explain empirical evidence/data/findings/observations/results from experiments, etc. (e.g. "they didn't believe Galileo because he didn't have any evidence for his theory").
13	Science can conflict with people's worldviews or political stances	Answers stating that people can resist new scientific ideas but specifically because these ideas can conflict with their personal/religious/cultural/political beliefs/worldviews. It's a more specific case of code #9, involving more personal stances than general scientific philosophies/ideas (e.g. some students citing Donald Trump's approach towards some scientific matters as an example).
14	Disagreement between scientists can occur because science is still in development	Answers stating that it's common for scientists to disagree specifically because we don't know everything about science/world yet, so many things are still to be studied and debated among them (e.g. "challenges and oppositions to new scientific theories still exist today because lots of pieces of the world have not been scientifically discovered").
15	Scientists have authority and power over knowledge about the world	Answers stating that people believe/agree with something said by scientists because they are scientists and they know what they are doing, because they are right (e.g. "they started believing in Galileo because he was right").
16	Scientific theories have to be well explained/founded	Answers stating that scientific theories/ideas must be well explained, it has to "make sense", must be detailed or "more scientific". There's a component here strongly connected to the power of the scientific rhetoric and to how scientists communicate their ideas to others, how they make themselves understood (e.g. "Tom's theory is better because he went into more detail").
17	Scientific theories are rarely opposed nowadays	Answers stating that nowadays scientific theories/ideas rarely face oppositions.
18	Science involves resilience and hard work	Answers stating that scientists work hard to develop their theories and carry out investigations (e.g. "people started to believe Galileo because he worked hard to prove he was right").

Table VII. Coding system for the NOS questionnaire – Implementation phase (cont.)

#	Final code/statement	Description
	Question 2	
#	**Final code/statement**	**Description**
19	Scientific ideas are shared/investigated/debated by a community of people	Answers stating that scientific theories/ideas can be collective investigated by different scientists, that they can share their findings/results and debate their ideas to get them right, to advance their knowledge/comprehension about a topic.
20	It can be difficult to gather evidence to prove a scientific idea	Answers stating that there are some cases where it can be difficult to have access to the evidence needed to inform a theory/idea and that maybe that could be the explanation for scientists' disagreement about something (e.g. "they disagree because it was such a long time ago, it is hard to find proof of what happened").
29	A scientific theory can be proved right or wrong	Answers clearly stating that scientific theories can be proved right/wrong in a later stage of research, with more evidence/studies, etc (e.g. "they started believing him because his theories were proved right").
37	People can distrust/resist new ideas	Answers stating that the general public can resist new ideas (e.g: "people were against the idea of something new")
	Question 3	
#	**Final code/statement**	**Description**
9	Scientists can resist new or different scientific ideas	Answers stating that scientists can resist new and/or opposite/different ideas/theories, especially if they follow another school of thought (e.g. "Scientists disagree about the dinosaurs because they believe in different things").
11	There can be different explanations, disagreement and competition among scientists	Answers stating that it's common for scientists to have different explanations/theories/ideas about the same phenomena/event (disagreements are part of life) and also that scientists can distrust other scientists' work. In some cases, answers are also related to scientists being jealous of each other, wanting to be always right, to be the first to discover something or to become famous (e.g. "they disagree because they are jealous of each other" or "they disagree because they want to become famous first").
12	A theory/model has to be strongly connected to empirical evidence/experiments to be accepted	Answers stating, in different ways, that scientific ideas/theories/models are based on and must explain empirical evidence/data/findings/observations/results from experiments, etc. (e.g. "they disagree because they don't have evidence to prove their point" or "to convince the others, they should get evidence to prove their theory").
14	Disagreement between scientists can occur because science is still in development	Answers stating that it's common for scientists to disagree specifically because we don't know everything about science/world yet, so many things are still to be studied and debated among them (e.g. "challenges and oppositions to new scientific theories still exist today because lots of pieces of the world have not been scientifically discovered").

Table VII. Coding system for the NOS questionnaire – Implementation phase (cont.)

Question 3		
#	**Final code/statement**	**Description**
16	Scientific theories have to be well explained/founded	Answers stating that scientific theories/ideas must be well explained, it has to "make sense", must be detailed or "more scientific". There's a component here strongly connected to the power of the scientific rhetoric and to how scientists communicate their ideas to others, how they make themselves understood (e.g. "Tom's theory is better because he went into more detail").
18	Science involves resilience and hard work	Answers stating that scientists work hard to develop their theories and carry out investigations.
19	Scientific ideas are shared/investigated/debated by a community of people	Answers stating that scientific theories/ideas can be collective investigated by different scientists, that they can share their findings/results and debate their ideas to get them right, to advance their knowledge/comprehension about a topic.
20	It can be difficult to gather evidence to prove a scientific idea	Answers stating that there are some cases where it can be difficult to have access to the evidence needed to inform a theory/idea and that maybe that could be the explanation for scientists' disagreement about something (e.g. "they disagree because it was such a long time ago, it is hard to find proof of what happened").
21	Scientific theories can be based on different types of evidence and interpretation	Answers stating that scientists may have conflicting ideas/disagreement because they were using different types of evidence to inform their research or because they were interpreting the same evidence in different ways.
24	Models can help to partially represent/explain a scientific idea or physical structure	Answers stating that scientists can use models to explain their ideas/theories about a phenomena/event.
25	Scientists and their work can be influenced by socio-historical contexts or personal opinions	Answers stating that maybe we can have different theories about a phenomenon because they were developed in different social, political, historical, economical contexts and by different people, with different opinions on the topic (e.g. "maybe they disagree because their theories were developed in different historical moments").
29	A scientific theory can be proved right or wrong	Answers clearly stating that scientific theories can be proved right/wrong. It can be a complement to code #26, when the student not only states that it's an unproven idea, but also that it could be proved in later stage, with more evidence/research, etc (e.g. "they have to prove the other theory wrong").
38	Some scientists are smarter than other scientists.	Answers connecting the acceptance of an idea with scientists' cognitive aspects, such as being "smarter" or "more intelligent".

Table VII. Coding system for the NOS questionnaire – Implementation phase (cont.)

Question 4		
#	**Final code/statement**	**Description**
12	A theory/model has to be strongly connected to empirical evidence/experiments to be accepted	Answers stating, in different ways, that scientific ideas/theories/models are based on and must explain empirical evidence/data/findings/observations/results from experiments, etc. (e.g. "they came up with their theories by doing experiments").
16	Scientific theories have to be well explained/founded	Answers stating that scientific theories/ideas must be well explained, it has to "make sense", must be detailed or "more scientific". There's a component here strongly connected to the power of the scientific rhetoric and to how scientists communicate their ideas to others, how they make themselves understood (e.g. "Tom's theory is better because he went into more detail").
19	Scientific ideas are shared/investigated/debated by a community of people	Answers stating that scientific theories/ideas can be collective investigated by different scientists, that they can share their findings/results and debate their ideas to get them right, to advance their knowledge/comprehension about a topic (e.g. "they could ask their teacher or other students to check their theories").
22	Scientific theories and models can be informed by previous knowledge/research on the topic	Answers stating that people/scientists can employ their previous knowledge/research about the topic to come up with their theories/models (e.g. "they came up with their theories using their prior knowledge").
23	It's important for scientific theories to be repeatable and generalisable	Answers stating that a theory must be repeatable (that is, it works every time it's applied to a phenomena/event) and generalisable (that is, it can be applied to other cases/scenarios and still explain them well). E.g: "Tom's theory is better because it works for both experiments".
27	A scientific theory is an idea, a prediction or a hypothesis about something scientific	Answers solely stating that theories are ideas, hypothesis or prediction about something.
28	A scientific theory is an explanation for events/phenomena	Answers stating that theories are explanations/ reasons for how/why something (event/phenomenon) works (e.g. "theory means that they have an idea or story behind why this happened").
29	A scientific theory can be proved right or wrong	Answers clearly stating that scientific theories can be proved right/wrong. It can be a complement to code #26, when the student not only states that it's an unproven idea, but also that it could be proved in later stage, with more evidence/research, etc (e.g. "theory is an idea that has yet to be proved right").
30	A scientific theory cannot be proved right or wrong	Answers clearly stating that scientific theories cannot be proved right/wrong. It can be a complement to code #26, when the student not only states that it's an unproven idea, but also that it could never be proved right in later stage, with more evidence/research, etc (e.g. "theory is an idea that cannot be proved").

Table VII. Coding system for the NOS questionnaire – Implementation phase (cont.)

Question 5		
#	**Final code/statement**	**Description**
1	Science involves investigating and expanding knowledge about people and the world	Answers related to 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, etc.
3	Science develops useful knowledge/things for everyday life, society and environment	Answers related to the usefulness of science. Answers that state that science can produce/create knowledge and/or technology/appliances that can inform/aid everyday life tasks/choices/routines/life quality, society in general and/or environmental scenarios (including solving problems).
4	Science is a subject matter/domain specific	Answers that associate science to specific subjects (e.g. Chemistry, Physics, Biology, etc.) and also disassociate it from others (e.g. Maths, Geography, History, etc.). Also, answers that associate science to specific topics/domains, such as "brain", "health", "universe" (e.g. "it's scientific because is about health") and disassociate it from other topics/domains, such as TV programmes (e.g. "it's not a scientific question because TV has nothing to do with science"). Here, answers are connected to a view of science as a subject bounded to specific areas of interest (usually related to school science subjects).
6	Science is about facts/right answers	Answers that are more specific related to science being interested in finding facts about things and/or fixed/right answers about specific questions and/or proving people wrong (e.g. "it's not scientific because is about choice and not facts").
7	Science is not related to everyday activities/technology	Answers where the student clearly that there is no relationship between science and everyday life activities or technology/appliances.
8	Science involves testing, finding evidence and/or making predictions	Answers that specifically state that scientific work is related to experimental tasks/scientific methods, such as carrying out tests, experiments, trials, finding evidence/data/facts, making observations and making predictions from data. It has a more experimental component in comparison to code #1.
19	Scientific ideas are shared/investigated/debated by a community of people	Answers stating that scientific theories/ideas can be collective investigated by different scientists, that they can share their findings/results and debate their ideas to get them right, to advance their knowledge/comprehension about a topic (e.g. "they could ask their teacher or other students to check their theories").

Table VII. Coding system for the NOS questionnaire – Implementation phase (cont.)

Question 6		
#	**Final code/statement**	**Description**
8	Science involves testing, finding evidence and/or making predictions	Answers that specifically state that scientific work is related to experimental tasks/scientific methods, such as carrying out tests, experiments, trials, finding evidence/data/facts, making observations and making predictions from data. It has a more experimental component in comparison to code #1.
10	Instruments and technology impact scientific discoveries/ideas	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, etc (e.g. "They can use equipments to develop this model of the Earth").
12	A theory/model has to be strongly connected to empirical evidence/experiments to be accepted	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, etc.
15	Scientists have authority and power over knowledge about the world	Answers stating that people believe/agree with something said by scientists because they are scientists and they know what they are doing, because they are right (e.g. "a scientific model is model that was approved by scientists").
22	Scientific theories and models can be informed by previous knowledge/research on the topic	Answers stating that people/scientists can employ their previous knowledge/research about the topic to come up with their theories/models.
24	Models can help to partially represent/explain a scientific idea or physical structure	Answers stating that scientists can use models to explain their ideas/theories about a phenomena/event.
33	Models are based on indirect evidence and/or estimations	Answers stating that models are developed using evidence/data gathered through indirect methods (such as scanning, fossils, rocks, etc.) and/or estimations.
34	Models are based on direct evidence/testing	Answers stating that models are developed using evidence/data gathered through direct methods (such as digging roles, sending people to the inside of the Earth, etc.).
35	Models are 100% accurate representations/explanations of a scientific idea or physical structure	Answers stating that scientific models are 100% accurate, that is, that they represent exactly what the phenomenon is/how it works.
36	Models are diagrams or images of something scientific	Answers stating that models are images/pictures/diagrams/physical representations of something scientific, usually (but not always) citing the difference in scale.

Appendix 16: Summary of the networks produced from the NOS questionnaire – Exploratory phase

Table VIII. Main features of the epistemic networks about NOS produced for each participant class

School	Class	# statements	Density of the network (%)	Most frequent statements (size of nodes)	Most central statements
A	Year 8 – mixed	33	17.2	• 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 involves investigating and expanding knowledge about people and the world; • 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; • A scientific theory can be proved right or wrong.
	Year 9 – set 1	31	19.8	• A theory/model has to be strongly connected to empirical evidence/experiments to be accepted; • It's important for scientific theories to be repeatable and generalisable; • A scientific theory can be proved right or wrong • Science develops useful knowledge/things for everyday life, society and environment.	• A theory/model has to be strongly connected to empirical evidence/experiments to be accepted; • It's important for scientific theories to be repeatable and generalisable; • There can be different explanations, disagreement and competition among scientists • Scientific theories have to be well explained/founded; • Science develops useful knowledge/things for everyday life, society and environment*.
	Year 9 – set 2	32	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.	• A theory/model has to be strongly connected to empirical evidence/experiments to be accepted; • A scientific theory can be proved right or wrong; • Scientific ideas are shared/investigated/debated by a community of people; • Science is a subject matter/domain specific*.
	Year 9 – set 3	30	13.1	• 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; • 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; • A scientific theory is an idea, a prediction or a hypothesis about something scientific; • It's important for scientific theories to be repeatable and generalisable; • Science is a subject matter/domain specific*.

Table VIII. Main features of the epistemic networks about NOS produced for each participant class (cont.)

School	Class	# statements	Density of the network (%)	Most frequent statements (size of nodes)	Most central statements
A	Year 10 – set 1	33	17.8	• 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.	• 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; • A scientific theory can be proved right or wrong; • Science involves investigating and expanding knowledge about people and the world*.
	Year 10 – set 2	29	14.3	• 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.	• 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; • Scientific theories have to be well explained/founded.
B	Year 8 – set 2	29	17.4	• 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; • Science is a subject matter/domain specific; • Scientific theories have to be well explained/founded.
	Year 9 – set 3	26	15.2	• 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; • There can be different explanations, disagreement and competition among scientists; • People can distrust/resist new ideas.
	Year 10 – set 1	32	20.8	• 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.	• 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; • It's important for scientific theories to be repeatable and generalisable; • There can be different explanations, disagreement and competition among scientists.

*Part of an isolated cluster

Appendix 17: Medicines TLP – Implementation phase

Table IX. Outline of the original TLP on Medicines

Lesson	Topic (content or NOS)	Activities
1	**- Natural resources** **- Medicines (active ingredient, extraction, natural versus artificial)** **- Scientific claims (testimony and evidences)** **- Collaborative and collective nature of the scientific work**	- Introduction to the topic (cards about early historical contexts – Egyptians, Chinese, native Americans, Arabic, Indian) – in groups - Sharing information from the previous cards + teacher talks about naturalist travels and their impact on medical practices (natural resources in science) - Compare and discuss herbal and conventional medicines (task 1) – in groups - Open debate about task 1 (collecting evidence, claims, testimony, natural versus artificial) - Task 2 (homework): research about a traditional plant used by a different culture (based on discussions about task 1)
2	**- Medicines (active ingredient, extraction, natural versus artificial)** **- Socio-cultural influences in science** **- Development of medicines (natural resources, animal/human testing)** **- Environmental issues and intellectual property in science** **- Ethics and economics in science**	- Peer review + discussion about task 2 - Teacher introduces modern techniques of drug production (natural versus artificial, active ingredient) - Video about biodiversity and drug production[136] - Task 3: biodiversity/native knowledge and drug production – in groups

[136] https://www.stem.org.uk/resources/elibrary/resource/34181/ugly-cures

Table IX. Outline of the original TLP on Medicines (cont.)

Lesson	Topic (content or NOS)	Activities
3	**- Development of medicines (quality control and animal/human testing)** **- Experimental design in science (fair testing, double blind, placebo)** **- Socio-political aspects, ethics and controversies in science**	- Teacher introduces next stages of drug production (animal/human trials, thalidomide) - Debate about drug trials (Ebola epidemic and animal testing) – task 4 - Task 5 (homework): research about the future of drug production
4	**- Development of medicines (quality control and animal/human testing)** **- Vaccines** **- Scientific claims (testimony, evidence)** **- Socio-cultural influences, ethics and controversies in science**	- Brief open discussion about task 5 - Talk about the history of vaccines (historical case – smallpox in different societies) and what they are (including MMR case) - Task 6: Debate about anti-vaccination movements

Outline of tasks

Task 1: Compare and discuss herbal and conventional medicines based on information about different drugs (e.g.: paracetamol versus garlic). Which one would you choose? Based on what? It will be followed by an open discussion about evidence, scientific claims, certification of scientific knowledge, natural versus artificial.
Task 2: Investigate a plant traditionally used by a specific culture (e.g.: Chinese medicine, Native American medicine, etc.) and write about it (poster, written work, drawings, etc). Further discussions will be carried out about the collective nature of the scientific work, exploitation of natural resources, socio-cultural influences in scientific work, etc.
Task 3: Cards about different household drugs that come from natural resources (plants or animals), with information about where these resources are found. Topics to discuss: impacts of environmental issues on drug production; ownership of these resources and knowledge (the country/community, the researchers, the pharmaceutical companies) and biopiracy.
Task 4: Debate about the Ebola epidemic and animal testing (task employed by teacher F during the Exploratory phase).
Task 5: Investigate the future of drug production (“why do we still have some diseases around?” – e.g.: drugs for tropical diseases, cancer treatment, AIDS, etc.).
Task 6: Debate about anti-vaccination movements.

Appendix 18: Magnetism TLP – Implementation phase

Table X. Outline of the original TLP on Magnetism

Lesson	Topic (content or NOS)	Activities
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 (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
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**	- Discussion of task 2 (HW) + open 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, Persian Gulf and Alexandria). Teacher briefly talks about its arrival in Europe and the impact on the Great Navigations and metal/coal exploration. - Task 3: Importance of Great Navigations to the world (in pairs) + plenary - Brief examples of modern uses of magnets

Table X. Outline of the original TLP on Magnetism (cont.)

Lesson	Topic (content or NOS)	Activities
3	**- Magnetic fields and Earth's magnetic field** **- The role of modelling in science** **- Observation and indirect evidence in science**	- Introduction to magnetic fields - Prompts: "Birds migration" + "how does a compass know where to point to?" - Discovery of the Earth's magnetic field (W. Gilbert's model) - Task 4 (homework): magnetic fields in nature
4	**- Magnetic fields and Earth's magnetic field** **- Science is tentative, creative and does not answer all the questions** **- The importance of observation and indirect evidence in science**	- Discussion about task 4 (HW) - "Can we see the Earth's magnetic field?" Discussion about the Northern lights and the Sun (observation and indirect evidence + Mary Somerville) - Task 5 (practical): Magnetic field with iron fillings (teacher's demo) + practical about magnetic field patterns (in groups) - Exam questions (if possible)

Outline of tasks
Task 1: Practical – test different materials for magnetism. Follow-up discussion about observations, indirect evidence and inferences in science.
Task 2: Find as many uses as possible for magnets around your home, identifying any magnetic materials. Use your findings to write a paragraph to explain where and why magnets are useful.
Task 3: Students discuss the possible impacts of being able to navigate around the world (1 economic, 1 scientific, 1 political, 1 everyday life).
Task 4: Find out about a natural phenomenon (on Earth or any other part of the universe) that is related to magnetic fields.
Task 5: Practical – experiment about magnetic field patterns with iron fillings.

Appendix 19: Evolution TLP – Implementation phase

Table XI. Outline of the original TLP on Evolution

Lesson	Topic (content or NOS)	Activities
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 info 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 natural selection and evolution - Task 1: survival of the fittest – in pairs
2	**- Natural selection and theory of Evolution II (implications)** **- Social and cultural influences in the production of scientific knowledge** **- The role of controversies, disagreements and processes of certification (peer review) in science** **- Relationship between evidence, explanation and theory** **- Relationship between science, ethics, economics, environment, etc.**	- Recap of natural selection and evolution ("Tree of Life" video[137]) - Task 2: Different opinions about the theory of evolution (cards) – class debate - 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) - Discussion about examples of different "uses" of Darwin's ideas in society - Task 3 (HW): family tree (organism of choice)

[137] http://www.wellcometreeoflife.org/video/

Table XI. Outline of the original TLP on Evolution (cont.)

Lesson	Topic (content or NOS)	Activities
3	**- Extinction** **- Relationship between science, ethics, economics, environment, intellectual property, etc.** **- Relationship between evidence, explanation and theory** **- The role of controversies, disagreements and processes of certification (peer review) in science**	- Discussion about HW (task 3) – focus on the future of the chosen organisms – connection with extinction - Initial discussion on what they already know about extinction ("what does extinction mean"?) - Video: "Extinction"[138] - Task 4: "Threatened, endangered, extinct" (examples of species) – cards in pairs + sharing with the class - Discussion about causes of extinction (summary of task 4) – worldwide examples - Video: "The story of extinction"[139] - Task 5: "Dinosaurs extinction" – information sheets in pairs + plenary
4	**- Preservation of biodiversity** **- Relationship between science, ethics, economics, environment, intellectual property, etc.**	- Recap on biodiversity (lessons on Medicines) – what it is, why it's important – connection with the idea of extinction - Discussion about conservation and preservation of biodiversity (ways to do it) - Task 6: "What do we preserve when we aim for 'biodiversity'?" - Class debate (based on task 6) about preservation of biodiversity – "preserving for what and for whom?"

[138] https://www.youtube.com/watch?v=36b9ox8iF24

[139] https://www.stem.org.uk/resources/elibrary/resource/34178/story-extinction

Outline of tasks

<u>Task 1</u>: In pairs, students receive random parts of organisms to build one of their own, thinking about in which environment this organism would be able to survive.

<u>Task 2</u>: In pairs, learn about different views on the theory of Evolution (religious, other scientific views). Debate these different ideas with the whole classroom, including discussions about scientific and non-scientific explanations, evidence and scientific theories.

<u>Task 3</u>: Choose an organism and carry out research on it, writing an explanation for how this organism has evolved over time, and how it is connected with the local ecosystem (link with possibilities of extinction).

<u>Task 4</u>: In pairs, learn about different organisms that are threatened, endangered or extinct. Discuss the differences between these 3 concepts and why these organisms are in this situation.

<u>Task 5</u>: In pairs, work with the information sheet about the extinction of the dinosaurs. Each pair will study and present one of the possible causes for the extinction (asteroid, volcano, climate change). Use this task to discuss ideas of evidence, explanation and theory (disagreement, different evidence and interpretation).

<u>Task 6</u>: In pairs, work on a preservation case to discuss the different perspectives (local, global, financial, environmental, etc) involved in preserving biodiversity. Follow-up discussion around “What do we preserve when we aim for 'biodiversity'?” and “Who benefits from it?”.

Appendix 20: Earth's resources TLP – Implementation phase

Table XII. Outline of the original TLP on Earth's resources

Lesson	Topic (content or NOS)	Activities
1	**- Earth's composition (metals)** **- Science and exploitation of natural resources** **- Relationship (and differences) between science and technology** **- Collaborative and collective nature of the scientific work**	- Recap on the periodic table and metals (interactive periodic table[140]) - Introduction cards: different uses of metals in different places (in pairs) - Based on these cards, recap about metals in nature ("where do they come from? Why are they so important?") - Plenary: Finding metals on Earth (explore interactive map[141]) - Q&A on natural sources of metal (mineral, ore, element, compound) - Video: the formation of gold[142] + talk about alloys - Task 1 (HW): metals in History
2	**- Metal extraction (I)** **- Social and cultural aspects of science (commercial aims, contextual influences, exchange and transmission of knowledge)** **- Science is tentative, creative and does not answer all the questions**	- Presentation/discussion of task 1 (HW) – issues/difficulties involved in metal exploitation – metal extraction - Discussion about history of metal exploration (Silk Road, Great Navigations) + history of metal extraction (different ancient techniques) - Introduction to extraction with carbon - Task 2: Extracting metals with carbon (practical)

[140] http://www.rsc.org/periodic-table

[141] http://www2.open.ac.uk/openlearn/periodictablephase2/elements-world.html

[142] https://www.youtube.com/watch?v=jf_4z4AKwJg

Table XII. Outline of the original TLP on Earth's resources (cont.)

Lesson	Topic (content or NOS)	Activities
3	**- Metal extraction (II)** **- Social and cultural aspects of science (commercial aims, contextual influences, exchange and transmission of knowledge)** **- Relationship between science, ethics, economics, environment, etc.**	- Recap on practical: metal extraction with carbon and reactivity series - Metal extraction through electrolysis (history and concepts) - Task 3: impact of metal extraction (in pairs) - Video: space mining[143] - Task 4 (HW): life expectancy of a metal
4	**- Recycling** **- Science and exploitation of natural resources** **- Social and cultural aspects of science (commercial aims, contextual influences, exchange and transmission of knowledge)** **- Relationship between science, ethics, economics, environment, etc.**	- Discussion about HW ("what happens to materials after they've been used?") - Connection of the HW with the idea of recycling (Q&A on "4R") - Task 5: History of recycling (different events) - Follow up discussion about task 5 + recyclable materials - Task 6: recycling processes (aluminium, plastic, carton)[144] - Group discussion about the positive and negative aspects of recycling

Outline of tasks
Task 1: Research the history of one specific metal, exploring: properties, timeline and uses by different cultures, commerce, abundance, etc.
Task 2: Practical about metal extraction using carbon.
Task 3: Analysis of some facts and statistics about the environmental and social impacts of metal extraction (in pairs).
Task 4: Choose 1 metal and research about its life cycle and life expectancy.
Task 5: Timeline of waste management and recycling.
Task 6: Each pair will be responsible for mapping one recycling process (aluminium, plastic, carton) showed by the videos and then share with the rest of the class.

[143] https://www.youtube.com/watch?v=lT11_2h6_LY

[144] Videos from Recycle Now: https://www.youtube.com/user/RecycleNowCampaign/videos