“I didn’t know how that could come to this curriculum”: teacher’s growth through the development of materials about Nature of Science

This article arises from a teaching experience at a state secondary school in London/UK that aimed at promoting a more culturally diverse teaching about Nature of Science (NOS) grounded on Global History of Science. Ideas from this field were employed to design of four different teaching and learning plans (TLPs) that linked NOS and content from the National Curriculum for Science in England through historical narratives. The elaboration of these TLPs was carried out as a collaborative experience between the researcher and a participant science teacher throughout one school year, following design principles to inform different cycles of development, teaching – at one classroom (26 students aged 12-13) – and reflection about these materials. Grounded on a qualitative approach to data generation (interviews and observational field-notes) and analysis, the main aim of this article is to explore how this researcher-teacher partnership has affected the participant teacher’s professional, personal and social growth. Findings from this teacher’s engagement with the development, enactment and reflection about these innovative teaching resources will be presented to illustrate how this type of experience can influence, for instance, teachers’ professional development, perceived self-efficacy around NOS teaching and ownership of novel teaching ideas.

Keywords: teacher growth, researcher-teacher partnerships, material development, nature of science, science education

Introduction

Several researchers and curricula have advocated the inclusion of Nature of Science (NOS) into school science in the past decades (Abd-El-Khalick & Lederman, 2000; Hodson, 2014; NRC, 2013; Bybee, 2014). While there are different views on what NOS is, there seems to be a consensus around its place is exploring, through sociological, philosophical, psychological and/or historical perspectives, the processes involved in the production of scientific knowledge. Authors (e.g. Forato, Andrade Martins, & Pietrocola, 2012) mainly argue that understanding science as more than its products is relevant to people living alongside these products, since it can generate a more realistic view of their benefits and limitations. Nevertheless, NOS implementation in regular science lessons still faces several obstacles ranging from teachers' knowledge about History, Philosophy and Sociology of Science (HPSS) to curricular, time and teaching resources constraints (de Berg, 2014; Höttecke & Silva, 2011; Lederman, 2007). In a recent review paper, Clough (2018) reflected on the state of NOS teaching by highlighting that work is still needed to identify strategies for overcoming these constraints and promoting long lasting impact on teachers' practices.

In the case of most innovations in school practice (e.g. teaching about NOS), educational researchers highlight that lack of teaching materials, constraints from institutional frameworks and teachers' self-efficacy beliefs are often the usual barriers (Roblin, Schunn, & McKenney, 2018; Ryder & Banner, 2013). In this context, Brown and Edelson (2003) argue that these innovations can only be successful if taking into account the role of the teacher in their development-implementation-assessment. Bell and Gilbert (2005) also suggest that teachers' participation in the design of teaching materials can affect both the sustainability of these new ideas and their self-efficacy beliefs and sense of ownership of these materials. Similarly, Clarke and Hollingsworth (2002) and Penuel, Allen, Coburn, and Farrel (2015)

explore the relevance of researcher-teacher partnerships to the innovations, also looking at how this type of experience impacts teachers' professional, social and personal growth.

Considering these links between collaborative approaches to educational innovation and teachers' growth, in this article I will explore a researcher-teacher partnership on the creation of teaching and learning plans (TLPs) that integrated NOS and content from the Science Curriculum in England. Arising from a larger study on NOS in school science, I will reflect here on how this partnership impacted the participant teacher, going beyond the identification of obstacles by describing strategies to overcome them and promote lasting effects on teachers' practices around NOS, as asked for by Clough (2018).

Literature Review

Nature of Science in Science Education

School science took a humanistic turn in the latter half of the 20th century when educators and reforms started to debate ideas related to 'science-technology-society' and to 'scientific literacy for all'. In this new scenario, authors (Abd-El-Khalick & Lederman, 2000; Driver, Leach, Millar, & Scott, 1996; Duschl, 2008; Hodson, 2014) advocate the inclusion into science lessons of discussions about how science and scientists produce knowledge (i.e. NOS). That would include, for instance, learning about the purposes of science, the nature of its knowledge ('epistemic dimension' – e.g. theories, observations) and its 'social dimension' (Driver et al., 1996; Erduran & Dagher, 2014). These authors emphasize the importance of NOS for students to appreciate science as a process of knowledge production with strengths and limitations, which can help to overcome anti-science ideas (i.e. recent 'alternative facts' movement) while also avoiding the other extreme of blind scientism (Gasparatou, 2017).

Although different suggestions of how NOS can be integrated into science teaching have been proposed – e.g. inquiry activities and historical cases (Allchin, Andersen, &

Nielsen, 2014) –, they have not been largely explored by school science. Two decades ago, Monk and Osborne (1997) cited that many projects were created but few were successful in bringing NOS to science teaching in England, mainly due to overwhelming concern about the products of science rather than its development. While contemporary studies described positive experiences (Guerra, Braga, & Reis, 2013; Höttecke & Silva, 2011; Levrini, 2014), recent reviews (e.g. Clough, 2018) reported that obstacles to NOS teaching still exist.

Obstacles to NOS teaching

Among these obstacles, there are those related to the 'translation' of knowledge produced by HPSS into teaching resources (Basu, 1999; Forato et al., 2012) and to teachers' lack of engagement with NOS over their professional learning (Lederman, 2007). A recent European project also identified the following challenges: lack of materials; teachers' skills, attitudes and beliefs; institutional constraints; and culture of teaching science; with the latter encompassing "noticeable features which embrace teachers, who are immersed in that culture, and strongly affects their curricular decisions and instructional behavior" (Höttecke & Silva, 2011, p. 296). In their project, the authors found this culture linked to: valuing a definite knowledge (only one way of answering a problem); focus on memorizing scientific facts; and teacher-centered lessons. Since effective NOS teaching often involves open-ended discussions, teachers as moderators of students' discussions (Deng, Chen, Tsai, & Chai, 2011), the work with NOS is then expected to produce change in this culture of teaching science, forcing the boundaries of more 'traditional' classroom practices.

In addition, institutional structures, such as curricula and assessment constraints, often stimulate innovation in a generic way through theoretical documents, with few practical experiences such as the development of teaching resources and professional development. In this case, NOS activities appear to be relevant but still dispensable (Höttecke & Silva, 2011).

Thus, we cannot ignore the obstacles to educational innovation when planning NOS proposals. Several authors (de Berg 2014; Höttecke & Silva, 2011) suggest that overcoming these challenges demands action from different actors, the design of resources to support long-term practices, and development opportunities for teachers. Nevertheless, Clough (2018) argues that Science Education has only recently started to explore strategies to overcome obstacles to NOS teaching. While proposals have been developed (e.g. Forato, Andrade Martins, & Pietrocola, 2012; Guerra et al., 2013; Henke & Höttecke, 2015), studies on promoting sustainable practices from teachers' perspectives are still lacking (Clough, 2018).

In this article, I will explore the impact of a researcher-teacher partnership on a teacher's practices and views about NOS teaching, looking at his professional, personal and social growth (Bell & Gilbert, 2005; Clarke & Hollingsworth, 2002). While this type of partnership is widely recognized as important for school innovations (Fullan, 2007; Penuel et al., 2015), accounts of collaborations are usually absent from the literature on NOS teaching, especially in relation to their transformative potential for science teachers.

Theoretical Framework

Teachers' growth and educational innovation: possibilities for NOS teaching

The implementation of new educational practices faces several institutional and agential obstacles. Among them, there is a 'top-down' approach to innovative materials aiming to 'translate' ideas into 'teachable' proposals without the input of teachers (Penuel et al., 2015). Brown and Edelson (1998, p. 6) argue that for innovations to be sustainable, teachers must "possess a 'big picture' view of the investigation, understanding how the given task fits in with the overall curricular goals", rather than mere 'appliers' of resources.

For teachers to "possess a big picture view" of innovative proposals, Ball and Cohen (1996) talk about understanding curricular materials as opportunities for teachers' learning.

Roblin et al. (2018) also comment on teachers' growth through their involvement in the creation of novel materials: beyond being a choice to avoid pitfalls of 'top-down' educational change (Fullan, 2007), this strategy can also foster teachers' professional development.

In their work on teachers' professional growth, Clarke and Hollingsworth (2002) talk about how educational change and professional development are linked by an 'Interconnected Model of Change'. This model recognizes that change in teaching (e.g. about NOS) does not only entail changes in teachers' beliefs about an innovative proposal: it has to be linked to experimentation (domain of practice) to offer the teacher experiences of implementation (e.g. teaching NOS) and to reflection about which outcomes from this experience (e.g. NOS or only on content) are salient to her practice and aims as a teacher (domain of consequence). Hence, they and other authors (e.g. Fullan, 2007) advocate educational change through cyclic processes of collaborative (external domain) development, enactment and reflection.

Bell and Gilbert (2005, p. 15) also mention the effects of being involved in the creation of innovative materials on teachers' personal growth, which includes "managing the feelings associated with changing their activities and beliefs about science education, particularly when they go 'against the grain'". This dimension is characterized by an initial need for self-growth, going through moments of dealing with constraints, ending up with her empowerment and increased perceived self-efficacy (Roblin et al., 2018).

Personal and professional growths are also connected with social growth (Bell & Gilbert, 2005), which 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" (Bell & Gilbert, 2005, p. 15). It involves moving from isolated work to valuing collaborative work and then seeking one's own collaborations. This is especially significant to educational change, where teacher's enactment in collaborative environments is key to successful innovations and to scale them up (Clarke & Dede, 2009; Fullan, 2007).

In this article I will explore indicators of teacher's growth (professional, personal and social) arising from a researcher-teacher partnership around the development of TLPs linking content and a specific view of NOS (i.e. intercultural). My aim is to identify findings that can address the lack of narratives about these collaborative works in the Science Education field.

An intercultural view on NOS: inputs from the Global History of Science

Several approaches have been suggested to include NOS in school science, and many involve History of Science (HOS) (Develaki, 2012; Levrini, 2014; Matthews, 2014). Arguments for the use of HOS highlight its potential to depict tentativeness, methodological pluralism and socio-cultural contexts in science (Allchin et al., 2014). Nevertheless, when reflecting about the types of historical narratives used in school science, some authors (Author, 2018; Erduran, 2014; Ideland, 2018; Sarukkai, 2014) question the extent to which HOS-based NOS proposals can promote a comprehensive understanding of the complexity behind scientific work and communities. With most resources based on specific cultural/geographical contexts (e.g. male European), important aspects of NOS (e.g. ethical, financial and political issues; exploitation of natural resources; collaborations and exchanges) remain underexplored.

In this scenario, this study involved the creation of resources incorporating a more culturally diverse view of NOS into school science using an 'intercultural model of HOS'. This model, grounded on the Global HOS field (Fan, 2012; Roberts, 2009), looks at modern science as a product of material/cognitive exchanges, collaborations and appropriations among different societies promoted by diverse historical-geographical contexts (e.g. Silk Road, and colonizing and imperialist projects). Lee (2018, p. 503) 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".

This intercultural model of HOS then situates specific cases within a wider cross-cultural perspective, moving constantly between micro and macro contexts (Author, 2018). Take, for instance, the topic of magnetism. In the project described here, the use of an intercultural approach to HOS linked local uses of magnetic properties in history (e.g. Greek, European, Chinese) to how material (e.g. sources of magnetic materials), knowledge and technology exchange among them enabled the development and spreading of the compass as a navigation tool, leading to global events like the Great Navigations and fostering even more circulation of knowledge and resources (e.g. medicines and minerals) (Author, 2018).

The challenge in this project was then not only to promote NOS teaching, but also to innovate in the view of NOS normally found in the field. My partnership with the teacher pushed us both to a territory of non-traditional historical narratives about science, resulting in TLPs that were novel not only for this teacher's practice but also for NOS teaching as a field.

Methodology

Research Design

The experience described here is part of a larger collaborative project between me (researcher) and a science teacher at a state secondary school, which aimed at creating and implementing teaching and learning plans (TLPs) based on a historical-intercultural perspective for topics from the Science Curriculum in England. The whole project was devised as a case study (Stake, 2005) to allow an in-depth investigation of the development and teaching of these TLPs, focusing on impacts of this experience on the teacher and of the TLPs on his students' views about NOS. While the latter has already been explored elsewhere (Author, in review), here I will explore the teacher's involvement in this project.

Inspired by a 'collaborative action-research'/'collaborative inquiry' approach (Sirotnik, 1988), my goal was to promote transformative change for the teacher as a

practitioner (and for me as a researcher) via collaborative research, enaction and reflection. I expected this approach to both increase the success of this experience (Roblin et al., 2018) and affect the teacher's personal, social and professional growth, addressing the question: What are the impacts of engaging with the elaboration of innovative resources to teach about NOS on the participant science teacher's professional, personal and social growth?

This was an iterative work based on design principles – 'planning', 'implementing' and 'evaluating' (Brown & Edelson 2003; Edelson, 2002): development of a TLP; teaching of this TLP; and reflection prior to developing the next TLP. Working with four TLPs (Medicines; Magnetism; Evolution; Earth's Resources) enabled us to diversify this experience with topics from three science subjects (Biology, Chemistry and Physics). The time between the teaching of each TLP was employed both for reflection about what had worked and what had not in the planning and teaching stages ('post-teaching' stage) and as a space for thinking about changes for the next TLP ('pre-teaching' stage). Each TLP was implemented at a specific time of the school year, involving 4-5 hours of teaching each.

Setting and participants

This study was undertaken at state school A in London/UK. This is a secondary, non-faith and mixed-sex school (860 students, 55% with English as a second language) with a growing engagement in innovation. Among its science teachers, Ian[i] was invited to participate due to his interest in NOS teaching. He is a Biology specialist, male, White British with around nine years of teaching experience. His expertise in Biology was in itself an important aspect of this research: since he was expected to teach Chemistry and Physics topics as a lower-secondary teacher, I would then be able to explore obstacles and affordances of this partnership to his work outside his subject specialism. Ian had no prior training in NOS teaching or HOS, but during our first conversation he mentioned that teaching 'how science works' was something

he has been keen to try out but had never had the opportunity and support to do so. The participant classroom was his only lower-secondary group in that school year (convenience sampling): 26 mixed-abilities year 8 students aged 12-13 (demographic information[ii] in table 1). This group had two weekly single lessons of 1h each with Ian. [TABLE 1 HERE]

The Teaching and Learning Plans (TLPs): an overview

During our partnership, Ian and I developed four TLPs about topics from the curriculum for year 8 Science (in order: Medicines; Magnetism; Evolution; Earth's Resources) and our aim was to link NOS and regular content through historical narratives based on Global HOS:

- Medicines TLP: accounts about the history of medicines and uses of natural resources;
- Magnetism TLP: history of the relationship between science and technology, material sciences, maritime travels, mining and Earth's magnetic field;
- Evolution TLP: historical narratives and links between naturalist travels, natural resources, extinction and the development of explanations about natural selection and evolution;
- Earth's Resources TLP: accounts on metal usage/exploitation in different societies and on the links between these natural resources, environment, chemical knowledge and technology.

After choosing historical narratives to inform the TLPs, Ian and I moved onto selecting NOS aspects (Erduran & Dagher, 2014) arising from these narratives that could be linked to the regular content. A 'spiral approach' was adopted over the school year, allowing for an overlap of NOS aspects within and among the TLPs: as seen in table 2, NOS elements were part of different lessons and topics, all connected by similar historical-epistemological narratives and looking at scientific work from a global perspective. [TABLE 2 HERE]

The inclusion of these NOS aspects into the lessons and their link with regular content was done explicitly through planned follow-up questions about the narratives/tasks proposed

(see examples in figures 1 and 2). These questions did not aim to check students' ideas in a declarative way, but to foster open discussions about NOS based on 'assessment for learning' (Black & Harrison, 2004). Other pedagogical strategies used were: direct teaching, practicals (e.g. copper/iron extraction in the Earth's Resources TLP), group debates (e.g. animal testing in the Medicines TLP) and homework (e.g. endangered species in the Evolution TLP), all looking to explicitly connect content (e.g. Earth's magnetic field and the compass) and NOS aspects emerging from the adopted intercultural perspective (e.g. scientific/technological development and social-political exploration of the world). [INSERT FIGURES 1-2 HERE]

Data generation and analysis

The effects of this experience on Ian were explored through a qualitative approach and different methods of data generation used throughout our whole partnership:

- Audio-recordings of the pre-teaching sessions (unstructured conversations): two planning/development sessions of 2h (4h in total) for each TLP.
- Audio-recordings of the post-teaching sessions (semi-structured interviews): a reflection session of 2h after each TLP and a session of 2h at the end of the year. These interviews were used to stimulate Ian's reflections on the experience and to cross check my own impressions.
- Field-notes about the teaching TLPs (classroom observations): all lessons based on the TLPs were observed (totaling 22h, with an average of 5h/topic) and notes were taken on adaptations and transformations of the materials and on students' participation.
- Field-notes about Ian's immediate impressions about each lesson (informal conversations): notes were taken about informal chats between Ian and me immediately after each lesson.

Audio-recordings of pre-teaching sessions and semi-structured interviews were transcribed verbatim, while field-notes taken during the classroom observations and about our

informal conversations at the end of each lesson were kept in the form of a research journal. By using a multi-method approach I aimed not simply to 'interrogate' Ian's work with the TLPs (e.g. observations and final interview), as often done by 'implementation studies', but rather to explore his professional, personal and social growth throughout this experience.

Data generated were then analyzed as a set of different types of data informing a multi-layered understanding (Scott, 2010) of how the development and implementation of these TLPs came about from Ian's perspective, with attention to how it impacted his professional, personal and social growth. To make sense of this experience, findings will be organized in this article according to the stages of our work: development ("Working with the teacher: exploring HOS, NOS and pedagogical strategies"), enactment of the TLPs ("Teacher's use of the TLPs") and reflections about this experience ("Teacher's impressions about the experience"). When examining these stages, I looked for indicators of professional (e.g. use of new pedagogical strategies; knowledge growth about NOS/HOS), personal (e.g. ownership of the TLPs; perceived self-efficacy) and social (e.g. understanding the relevance of collaborative work; sharing strategies) growth, as informed by my theoretical framework.

Data analysis was carried out under a qualitative-interpretive approach (Dey, 1993), with comparisons between our work on each TLP and in different stages (development, enactment and reflection) and exploration of agential (e.g. comfort with subject knowledge) and structural (e.g. curriculum/time constraints) aspects behind these findings. In keeping with the ethos of our partnership, the trustworthiness of findings generated under this approach was ensured by a constant triangulation between the interpretations I was making as a researcher and Ian's own reflections and interpretations. In addition, I also endeavored to position these findings within the field of (science) educational research through a constant engagement with different literature – a process of placing 'setting-specific' interpretations within a broader body of research (Robert Isaksen, 2016; Scott, 2010).

Main findings and discussions

One of my aims in this project was to explore the effects of being involved in the design and implementation of TLPs for NOS teaching on the participant teacher's professional, personal and social growth. In the next subsections, some of these findings will be explored.

Working with the teacher: exploring HOS, NOS and pedagogical strategies

Pre-teaching sessions happened over two days, including discussions about HOS, NOS and pedagogical strategies. They were used for creating these TLPs and as learning moments for Ian and for me (as an educational researcher). At the first pre-teaching session, we explored Global HOS narratives that could ground the material, NOS aspects linked to them and activities that could address both NOS and content. This unstructured work aimed to familiarize Ian with historical-epistemological knowledge – the educational dimension – and to exchange ideas of historical narratives/examples that could be explored in the lessons and tasks – the procedural dimension (Roblin et al., 2018).

The second session consisted of in-depth work on historical-epistemological ideas that would be part of the TLP, with special attention to slides and tasks initially planned in the first meeting. By going through these materials, we engaged more fully with HPSS aspects related to the TLP, being this a space for knowledge growth about HOS/NOS for Ian (Clarke & Hollingsworth, 2002). As a researcher, this close work with him pushed me to broaden my historical research for diverse narratives and examples according to suggestions Ian was bringing to these meetings – a moment of knowledge growth for me as a researcher –, and to look for different strategies for transposing HPSS knowledge to the specific context of his classroom and curriculum – practice growth as a researcher (Clarke & Hollingsworth, 2002).

During the second development session for the Medicines TLP (the first topic), Ian mentioned to be happy with our plan to have these lessons guided by questioning (Q&A), an

effective pedagogical strategy for NOS teaching (Clough, 2008) – he was confident that this approach would make this experience more interesting to his students, since they were usually keen to engage with questioning. It is worth remarking that while he favored a Q&A approach in his normal practice, he was not used to planning it, mainly adopting an 'on-the-go' strategy. This would then introduce a new aspect into his practice, linking professional growth to practice growth (Ball & Cohen, 1996; Clarke & Hollingsworth, 2002).

At this pre-teaching stage for the Magnetism TLP, Ian also mentioned his comfort with our collaboration and his learning about science, NOS and subject content. He talked, for instance, about how he had previously struggled with this topic because he "had never learnt too much about it". He mentioned how these lessons were less creative than others mainly due to his low confidence in using different materials and preparing activities beyond those proposed by the textbook:

> Ian: 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.
> Researcher: It doesn't seem that you don't know a lot about magnetism, I remember your lesson last year [prior to this project], the kids were very engaged.
> Ian: I know enough, but with magnetism I feel like I probably teach this quite flat.
> Researcher: What do you mean by flat?
> Ian: 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. *(Magnetism TLP, pre-teaching session)*

Ian was then hopeful that this TLP would give him more confidence to be less "flat" when teaching this topic. Here we can identify the impact of our partnership on his perceived self-efficacy when teaching outside his subject specialism (Roblin et al., 2018). Thus, there is

a potential of this experience being relevant not only to his professional growth around NOS teaching, but also to his personal growth, i.e. empowerment for teaching topics out of his comfort zone (Bell & Gilbert, 2005). Since one of my goals was to understand the potential of our work to his non-specialist teaching, his first impressions about this TLP were promising.

His personal growth was also seen when reflecting back about his teaching of the final topic (Earth's Resources). Despite being a Chemistry topic, he noted that he was feeling confident that this TLP had worked well and that he has been "able to teach it", positively impacting his students' learning of a science content that sites outside his specialism:

> Ian: What I felt with this one [Earth's Resources] was that there was more content that kids could access. If you imagine like a pyramid, the base of this topic is wider, so I feel quite often we were going further and further into new knowledge and I knew they were being able to follow and access it and I was being able to teach it. *(Earth's Resources TLP, post-teaching session)*

The increasing influence of this experience on Ian's perceived self-efficacy seem to also have affected the spread of the TLPs at school A: after our work on the first TLP (Medicines), he started to share these materials with other teachers in his department. About that, Ian mentioned that these materials were "complete with comments and explanations" *(Medicines TLP, post-teaching session)* and gave "context" to lessons:

> Ian: 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 [narratives], and context in that perspective rather than application of this context. *(All TLPs, end-of-year interview)*

Henke and Höttecke (2015) and Roblin et al. (2018) talk about how learning moments involved in teachers' work with curricular materials (part of their professional growth) can impact both their perceived self-efficacy (part of their personal growth) and their own views of science education. In turn, these new views (a change in the teacher's 'personal domain'), linked to enactment of new practices (the 'practice domain', i.e. actively teaching the TLPs) and reflection about them (the 'external domain', i.e. collaboratively reflecting about their creation and enactment) (Clarke & Hollingsworth, 2002), can also affect the scaling-up of innovative experiences and, more broadly, the teacher's social growth: moving from working in isolation to initiating his own collaborations and conversations with colleagues. Ian's decision to share the TLPs with others then illustrates the potential of researcher-teacher collaborations in material development to educational change through both professional growth (as usually found in the NOS teaching literature) and social growth.

Teacher's use of the TLPs

During this experience, Ian did not change the original TLPs greatly, but mainly adapted them to what was happening in the classroom – an 'improvisation' type of change (Brown & Edelson, 2003). Most transformations consisted of dedicating more/less time to discussions or tasks than originally planned, and referring to more examples to enrich the lessons and to address students' contributions. Ian seemed very aware of these in-lesson transformations during his teaching: in our informal chats at the end of these lessons, he would often highlight things he thought to have worked well and what he had changed from his original plan. This high level of awareness can be linked to his deep understanding of the TLPs and goals of each activity and follow-up discussion. And this can signal not only his professional growth (on intercultural perspectives and NOS teaching), but also his personal growth, as seen in his increasing ownership of these materials and confidence in adapting and adding to them.

Among changes observed, there was time management in classroom discussions, a common issue in open-ended NOS teaching (Höttecke & Silva, 2011). At the end of lesson 1 - Medicines TLP, for example, students had to work on a task about herbal and conventional medicines. However, while he applied this task as planned, he did not work on the follow-up Q&A as expected. When asked about it, Ian cited the lack of time to cover parts of the TLP, which he attributed to his tendency of being "carried away" by his students' high level of engagement *(Medicines TLP, field notes about impressions at the end of lesson)*. Since he was keen to stimulate his students' contributions and participation, most adaptations of the TLPs were linked to balancing original plans and students' engagement with the lessons.

After lesson 2 of this TLP, he changed his approach by selecting fewer but more diverse volunteers to participate with their own contributions and in the Q&A. This was done throughout the rest of the year and it seems to have helped him to engage with students while still managing time constraints. His awareness of how different pedagogical strategies could be used within the TLPs then hints to a growth in his familiarity with and resourcefulness around these materials, both at historical-epistemological (knowledge growth) and pedagogical (practice growth) levels (Ball & Cohen, 1996; Clarke & Hollingsworth, 2002).

In lesson 2 of the Magnetism TLP, for instance, he had planned a Q&A on the links between science and technology as a follow-up from a 'magnetic materials at home' task, but on the day he opted to move on to the planned topic of 'magnetic forces'. At the start of lesson 3, however, he introduced these links between science and technology into his recap of lesson 2, linking it with the compass, having the discussion planned for lesson 2 in lesson 3.

He continued to adapt his lessons against time constraints more confidently during the Evolution TLP, which he did not expect "to be very debate-heavy topic, but there was so much debate to 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" *(Evolution TLP, field notes about*

impressions at the end of lesson). Having no time left to discuss a video about Alfred Wallace works (end of lesson 1), he mentioned that he was planning to start the next lesson by recapping Charles Darwin's works and then connect him to Wallace. That indeed happened at the start of lesson 2, where he linked different people working on the field at that time.

Therefore, as his experience with the TLPs progressed, he seemed to be getting more comfortable with this adaptive work, balancing time constraints and students' participation. This can be linked to his practice growth in NOS teaching and a classroom chat at an Earth's Resources lesson (the last topic) about access to minerals illustrates how he balanced students' participation with content for that lesson (metal extraction) in an open-ended way:

Ian: How do you think they found out about their existence in difference places?

Student G: Through trading?

Student H: Ah yeah, with Medicines [TLP], there was the Silk Route.

Student I: Yes, with the compass [Magnetism TLP] as well.

Ian: What else can happen to spread the knowledge?

Student J: You can navigate around the world and visit different parts.

Ian: 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.

Ian: Why do you think it took people a while to find these materials? How come even today there are still some metals that we've only recently started to use them?

Student J: Because we didn't know where they were?

Student L: Some natural barriers?

Student M: Other people who live in the places.

Student H: They might know more about the metal and how to get it from nature.

Student I: Where to find it and how to get it from nature.

Ian: Great! We call that ‘extraction’. *(Earth’s Resources TLP, field notes from lesson)*

Ian’s growing familiarity with these materials seems to have also impacted his and ownership of the TLPs: while advancing through this experience, he started to increasingly add more examples and questions to the original plan not only for Medicine and Evolution (his subject specialism) but also for Magnetism and Earth’s Resources. Among these, there was his work with NOS, which evolved to a point where he was linking NOS aspects and questions asked by his students ‘on the spot’. In the Evolution TLP, for instance, he deepened the original questions about race and eugenics by challenging students to think about what “making rational decisions” means and about the use of science in social decision-making.

Edelson (2002) and Roblin et al. (2018) argue that innovative materials organized in a long-term and interconnected approach (instead of as stand-alone resources) are usually more efficient not only for students’ learning, but also for teachers’ knowledge and practice growth – i.e. professional growth – and perceived self-efficacy and ownership of these innovations – i.e. personal growth. Ian’s work with these TLPs illustrates this potential of a long-term and coherent approach to material development that goes beyond one or two specific resources, allowing for cyclic enactment and reflection (Clarke & Hollingsworth, 2002; Fullan, 2007).

Teacher’s impressions about the experience

Ian’s impressions about our work with the TLPs were investigated through quick chats at the end of each lesson, a follow-up interview after the teaching of each TLP, and one interview at the end of the school year. Overall, he seemed happy with students’ participation and learning and with his own work on the TLPs, as illustrated by some comments: “I’m surprised at how engaged they remained […] and clearly they are gaining some sort of confidence from that I’d say” *(Medicines TLP, post-teaching session)*; “The activities were great and the resources were great” *(Evolution TLP, post-teaching session)*; “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" *(All TLPs, end-of-year interview).*

At the end of the Medicines TLP, when asked if he was still feeling comfortable with our collaboration after teaching with the material for the first time, Ian stated that he had not seen any big issues. This perception seems to have continued throughout the other TLPs:

> Ian: 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. *(Magnetism TLP, post-teaching session)*
>
> Ian: So with this topic, despite being Chemistry, I feel students were able to access so much of it, to a deeper and new level of knowledge. So they were more prone to ask questions. *(Earth's Resources TLP, post-teaching session)*

About the Magnetism TLP, Ian described the expectation that his students would perform well in their exam about that topic, an interesting statement if we consider his initial low self-esteem about teaching Magnetism, as already mention here. Similarly, when reflecting back about the Earth's Resources TLP, Ian mentioned his students' engagement with a deeper level of knowledge than what he had been used to. Linking these comments to the fact that these topics site outside his subject specialism (Biology), this is a promising finding around the potential of partnerships like ours to teachers working outside their original background.

In addition, when talking about what had worked well during the school year, Ian specifically mentioned, after the Magnetism and Earth's Resources TLPs, how the narratives behind the TLPs (i.e. the intercultural model of HOS) worked well for teaching these topics

as a Biology teacher, since these topics were presented and discussed as nature-related and with local and global implications. This view about the links between his efficacy in teaching Chemistry and Physics topics and the global narratives employed in the TLPs hints to the potential of the intercultural model of HOS to teachers' perceived self-efficacy when teaching outside their subject specialism: it can offer new resources and historical-epistemological knowledge to ground more in-depth and creative teaching of different scientific content.

In addition, working on the development of TLPs based on this 'global' take on scientific development seems to have not only expanded his knowledge about HOS and NOS (knowledge growth), but also allowed him to experiment with practice growth around NOS teaching, which has in turn affected his personal growth around his perceived efficacy:

> Ian: 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 realize 'how science works' was lacking. [...] As a trainee I was just like wanting to crack up how to deliver content and manage behavior, and that was it. [...] So since then I've ignored 'how science works' for five years. [...] 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. *(All TLPs, end-of-year interview)*

Thus, after engaging with planning and teaching lessons linking NOS and content, Ian seems to have realized the positive aspects of teaching scientific knowledge as a coherent mix between 'process' and 'product', an approach advocated by many in the field of Science Education (Driver et al., 1996; Forato et al., 2012), but that still faces a difficult insertion in school science. Having NOS as part of his lessons gave him opportunities to link different ideas from different lessons and topics, bringing structure to his course throughout the year:

> Ian: 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, and how different content are linked in the natural world. *(Magnetism, post-teaching session)*

He also commented that the use of follow-up questions and the organization/structure of these lessons, specially being able to plan this work with NOS, had showed him the value of having NOS embedded in his teaching and not only to fill in the gaps of a specific content. In our final interview, he summarized his main learnings from this experience:

> Ian: [I learned] 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. *(All TLPs, end-of-year interview)*

Lastly, it is important to notice how Ian's personal and professional growth around NOS teaching (including outside his subject specialism) neatly summarized above seem to have both been influenced by and impacted his social growth (Bell & Gilbert, 2005): from his everyday and isolated routine within his Science Department, he started to actively extend and share the TLPs with his colleagues. Ian's specific development in the social dimension then meant that the ideas and strategies we had worked on together were now being advocated by him, a relevant finding for future aims of scaling up experiences of NOS teaching through the proposed intercultural model of HOS.

Discussion

In a recent review paper about NOS teaching and learning, Clough (2018, p. 4-5) indicated areas that still need to be explored, such as: how to inculcate the need for NOS in practice among teachers; how to prepare teachers to overcome constraints to teach NOS; and more empirical work on classroom implementation of NOS and on teachers' professional development.

While I do not presuppose to have definite answers to these points, I believe they bear a close connection to how teachers take part in NOS teaching experiences and that the type of work Ian and I carried out around the TLPs (a researcher-teacher partnership) can be the way forward. Here I agree with Penuel et al. (2015) that traditional classroom-based interventions that adopt the 'translation model' often do not fully address the usual obstacles (e.g. time and curricular constraints, self-efficacy beliefs) to educational innovation, and if we aim at exploring the points raised by Clough (2018), investigations and material development in the field of NOS teaching need to take these complexities into account through engaging teachers more fully in the innovation process.

When creating the TLPs, working with Ian aided me in 'translating' historical-epistemological research (intercultural model of HOS) into suitable activities, narratives and pedagogical strategies. While I cannot deny a certain degree of the 'translation model', the key aspect of this partnership was 'mutual learning' (Penuel et al., 2015): I was not simply taking HOS to Ian, but he was guiding our work based on his experiences and knowledge of his students. Thus, as a researcher, I was constantly learning about pedagogical and curricular realities, and reflecting on strategies for transposing HPSS knowledge to school science.

We then constantly tried to find a middle-ground approach between 'too tight' (top-down) and 'too loose' (bottom-up) strategies of educational change (Fullan, 2007) by working in a space of continuous professional exchanges between researcher and teacher.

Our pre-teaching and post-teaching meetings and informal chats at the end of each lesson were then spaces for professional interactions and exchanges about the TLPs, pushing both of us further in relation to the innovative ideas we had been trying to explore. As a researcher, I was constantly looking for interesting examples, narratives and their connections with the curriculum to bring to our meetings. Meanwhile, Ian was regularly re-thinking the salient outcomes of his lessons and his approaches to NOS, HOS and Q&A, and proposing ways of adapting this historical scholarship to his reality. Thus, part of my answer to Clough's (2018) reflection about NOS teaching resides in this 'mutual learning' model of collaboration between researcher and teachers, in which teachers do not simply learn more about HOS and NOS and their importance to school science, but they also reflect upon their regular practices by working on the development of these innovative ideas.

While teachers' engagement with the production of curricular materials can positively impact educational innovation (Ball & Cohen 1996; Bell & Gilbert, 2005), regular enactment of these materials is also relevant. The informal chats at the end of each lesson and the post-teaching meetings at the end of a TLP were of great importance to the continuity of our partnership, especially in relation to necessary changes after enacting these materials. Ian'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 classroom experience from teachers' perspective. More than simply being in accordance to the design principles adopted as a methodological strategy in this study, this 'reflection-upon-action' approach (Schön, 1991) allowed for an intensive process of growth.

Several moments of teacher's knowledge growth and practice growth were identified throughout this project: a mix of enactment and reflection seems to have enabled Ian to conquer some of the constraints from his reality and to further develop his expertise as a science teacher, while also showing him the value of bringing HOS, NOS and diverse

examples to his lessons. Here we could look at Ian's professional growth not simply as him working out how to introduce NOS into his lessons, but actually as him realizing that NOS is integral to scientific knowledge and to the understanding of any science topic. And that leaving HOS, NOS and diversity out of his lessons is a pedagogical act (Bernstein, 1996) that gives his students only a partial view of scientific knowledge and development.

Ian's personal growth (Bell & Gilbert, 2005) was also identified during this experience, especially in relation to his perceived self-efficacy. The impact of developing and enacting these TLPs on his views about himself as a science teacher was seen, for instance, during our meetings: some of his concerns about his ability to teach topics outside his subject specialism had been touched upon before our work, but at the end of the year he mentioned his comfort with all TLPs. Therefore, producing, teaching and reflecting about the TLPs in a collaborative space where knowledge and strategies were shared seems to have taken Ian through a process of personal growth intrinsically linked to his professional and social growth (as illustrated by his decision to advocate these TLPs to other teachers at school A).

Going back to Clough's (2018) call for research in NOS teaching, these findings seem promising to collaborative approaches in the development of curricular materials and in teachers' growth through this type of experience. 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).

Conclusion

Findings from Ian's engagement with this study can be valuable to science teacher education. They could be further explored in teacher development programs to better understand the

affordances of collaborative approaches to teachers' growth around NOS teaching, as opposed to solely top-down, one-size-fits-all initiatives. However, as with any small-scale study, questions about scalability and relevance of these findings to other contexts will arise, since this experience happened at a specific setting, with one teacher and one classroom.

Roblin et al. (2018) identifies some indirect indicators of potential for scalability that can be found in small-scale studies: sustainability and spread. In relation to the sustainability of this experience [i.e. "maintaining these consequential changes over substantial periods of time" (Clarke & Dede, 2009, p. 354)], whether and how Ian kept working with these TLPs could be explored in the future stages of this project. These results could offer insights into its sustainability and long-term effects on his growth as a science teacher. In addition, Ian's active work in sharing and advocating these TLPs to other science teachers is a sign of a 'spreading process' occurring at the local level. Whilst this teacher-teacher sharing is helpful for scaling up the TLPs, it is worth remembering that educational change is multidimensional (Fullan, 2007): enactment and feedback in a collaborative space are important, especially if we consider that other teachers at school A might have different starting points in relation to HOS, NOS, etc. Since these teachers are not benefiting from the same collaborative environment as originally experienced by Ian, it is difficult to predict how the spread of these materials will happen. Possibilities from the development of communities of practice [e.g. Trabona, Taylor Klein, Munakata, & Rahman (2019)], with Ian acting as mentor for his colleagues could then be considered by similar projects in the field of NOS teaching.

¡ Pseudonym.

ii Self-declaration as part of an initial demographical (and anonymized) questionnaire.

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