



A Starting Point: Provide Children Opportunities to Engage with Scientific Inquiry and Nature of Science

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Abstract

This paper explores the effect teachers' participation in a targeted inquiry-based/nature of science (NoS) continuing professional development programme had on Irish primary children's experiences of scientific inquiry and developing conceptions of NoS. Data were gathered from 459 children from 10 Dublin schools. The findings revealed that their teachers' engagement with the targeted professional development programme had positive effects on the children's experiences of scientific inquiry and on their developing NoS conceptions. It was apparent that professional development methodologies were effectively implemented throughout the school year, which led to a significant increase in these children's engagement with more child-led inquiry-based approaches and a significant decrease in engagement with more teacher-led methodologies. Furthermore, engagement with the professional development methodologies resulted in the children developing more elaborate conceptions regarding 'general aspects' of NoS. The findings are significant in that they add to the growing body of literature that asserts that pedagogy regarding 'general aspects' of NoS is an appropriate starting point in supporting the development of young children's NoS conceptions. Furthermore, engagement with the programme methodologies during school science enabled the children to make sense of science in their everyday lives. Science education policy documents worldwide highlight the importance of scientific literacy and suggest that if students are to become scientifically literate it is essential that they develop their understanding about the processes of science and the type of knowledge science produces and have the ability to apply this scientific knowledge in every day contexts. The findings in this study are significant in that it is apparent that engagement with inquiry-based and NoS pedagogies appeared to have been a very good starting point in supporting the development of these young children's scientific literacy skills.

Keywords Nature of science · Scientific inquiry · Scientific literacy · Primary science pedagogy

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Introduction

This paper explores Irish primary children's experiences of scientific inquiry and learning about nature of science (NoS) as a result of their teachers participating in a targeted Inquiry-Based Science Education (IBSE) continuing professional development programme that emphasised explicit features of NoS. It explores the primary children's understanding about NoS and experiences of scientific inquiry and considers whether the professional development methodologies were effective in addressing misconceptions these children held about NoS.

Science education policy documents worldwide highlight the importance of scientific literacy and suggest that if pupils are to become scientifically literate it is essential that they develop their understanding about the processes of science and the type of knowledge science produces and have the ability to apply this scientific knowledge in every day contexts (Eurydice Network 2011; Organisation for Economic Co-operation and Development 2013). Much educational research has highlighted the importance of inquiry-based methodologies and NoS pedagogy in developing children's scientific literacy. With regard to inquiry-based approaches to learning science, it is apparent that the adoption of such approaches supports the development of children's scientific knowledge and skills, leads to increased interest and motivation in science, facilitates collaboration in school science and promotes critical thinking and problem-solving skills (Artique et al. 2012; Harlen 2012; Rocard et al. 2007). Research also highlights numerous benefits of teaching about NoS. For example, some suggest that learning about NoS enables children to understand the tentative and developmental NoS and science as a human activity, which makes science more interesting for children to learn (Abd-El-Khalick 2012a; Driver et al. 1996; Mc Comas et al. 1998). Others propose that pupils who leave school with sophisticated conceptions of NoS have a better understanding of scientific knowledge and the processes by which scientific knowledge is produced and have a better understanding of socio-scientific issues (Driver et al. 1996; Khishfe 2012; Lederman et al. 2014; Lederman and Lederman 2014).

However, there is considerable debate about what exactly children should learn about NoS. Much of the research conducted on NoS pedagogy for the past 40 or so years has focussed on particular tenets or features of NoS (Lederman et al. 2002; Mc Comas et al. 1998; Osborne et al. 2003) what Kampourakis (2016) refers to as the 'general aspects' conceptualisation of NoS (a conceptualisation that is based on a list of general aspects about science about which there is general consensus amongst science educators). However, in more recent years, this 'general aspects' conceptualisation of NoS has been the subject of much criticism as being too narrow an account of science that does not take into account the multifaceted nature of the different scientific disciplines (Erduran and Dagher 2014a; Irzik and Nola 2014). While acknowledging the above, advocates of the 'general aspects' account of NoS argue that it is a necessary starting point for developing children's conceptions of NoS and for addressing commonly held misconceptions children tend to hold about NoS (Akerson et al. 2013; Kampourakis 2016; Lederman and Lederman 2014; Van Dijk 2011). The 'general aspects' account of NoS is a key focus of this study.

Similar to primary science curricula throughout the world, social constructivist pedagogy underpins the current Irish Primary Science Curriculum (Department of Education and Science (DES) 1999) and a scientific approach to problem-solving, understanding and constructive thinking is highlighted throughout. However, there is only one brief reference to NoS that appears in the general introduction "the children should learn about NoS ..." (DES 1999, p.8) and there are no curriculum objectives that explicitly refer to NoS learning. Irish research has

shown that Irish primary teachers do not teach about NoS when implementing the primary science curriculum and Irish primary teachers tend to hold misconceptions about ‘general aspects’ of NoS Murphy et al. 2007a, 2015).

There are also concerns in Ireland regarding learning in primary science. A national study of Irish primary children’s experiences of school science revealed that while children in Irish primary schools are engaging with hands-on science to some extent, there still appears to be an overemphasis on the use of more teacher-led, inductive approaches to science where ‘child-led, autonomous investigations appear to be used relatively rarely as a hands-on strategy’ (Varley et al. 2008, p. 192). This same national study also found that Irish children were having little if any experience of learning about NoS while engaging with the science curriculum and that pupils’ means of linking their scientific experiences to everyday and to the world of science and technology are not being fully fostered (Varley et al. 2008).

With these concerns in mind, an intensive targeted NoS through IBSE professional development programme was developed and piloted with 20 primary school teachers, teaching in 10 Dublin schools in the Republic of Ireland. The framework for this professional development was based on Desimone’s (2009) framework for effective professional development and the content was aimed at developing the participants’ pedagogical content knowledge (PCK) (Shulman 1986) in NoS and inquiry-based approaches to teaching science. The effect this professional development programme had on the teaching and learning of science in Ireland was examined in two phases: phase 1 examined the effect on participating teachers and phase 2 (presented here) the effect on children’s learning. The findings from phase 1 of the study (the effect participation in the programme had on teachers) is presented in a previous paper (Murphy et al. 2015). During this phase, data were collected from the teachers via pre-/post-questionnaires, pre-/post-teacher interviews and reflective journals. The teachers’ responses in the questionnaires, interviews and reflective journals revealed a shift towards more inquiry-based approaches to teaching science with a strong focus on explicitly developing children’s NoS understanding through engagement with scientific inquiry in school science. Throughout the questionnaires, interviews and journal responses, all of the teachers reported that as a result of participating in the professional development programme, they felt more confident about teaching science through inquiry and about teaching NoS and that they reported frequently implementing the professional development methodologies in their classrooms. All three data sources indicated that the teachers reported that their participation in the programme had a positive impact on the development of their pupils’ scientific inquiry skills, their pupils’ experiences of working collaboratively in science class and on their pupils’ understanding of NoS (Murphy et al. 2015).

The current paper now considers phase 2 of the research and explores the children’s experiences of scientific inquiry and learning about NoS while engaging with the professional development methodologies. Specifically, this paper addresses the questions:

- How did teachers’ engagement with the professional development methodologies affect children’s experiences of scientific inquiry in school?
- In which ways did the professional development methodologies affect children’s developing conceptions about ‘general aspects’ of NoS?

The findings of this study are significant in that they contribute to the small body of research that examines whether primary teachers can effectively implement inquiry-based and NoS methodologies into practice. Secondly, the findings add to the growing evidence that affording

primary school children opportunities to reflect on and engage with activities related to ‘general aspects’ of NoS is effective in addressing children’s preconceptions about NoS and is an appropriate starting point for developing children’s conceptions of NoS. Furthermore, the combination of engaging with and reflecting on their experiences of engaging with scientific inquiry and on their conceptions of NoS appears to have enhanced these primary children’s scientific literacy.

Literature Review

A common goal of science education curricula worldwide is to support the development of scientific literacy. International policy documents (for example, Eurydice Network 2011; National Research Council 2012) highlight the importance of scientifically literate citizens and the vital role school science plays in equipping children with the requisite knowledge and skills to deal with and make sense of the socio-scientific issues that they will encounter as citizens. It is also worth noting that scientific literacy is also a central component of international assessments of pupil attainment in science (Organisation for Economic Co-operation and Development (OECD) 2013). Bybee (1997) has argued that the term ‘scientific literacy’ has been used in various ways, as a definition, as a slogan or as a metaphor. When ‘scientific literacy’ is used as a slogan, it serves to provide science educators with a purpose for science education. As a metaphor, ‘scientific literacy’ is concerned with having a good knowledge of science and being well-informed on scientific issues (Murphy et al. 2007b). Roberts (2007) presents two ‘visions’ or components of scientific literacy. The first vision of scientific literacy for Roberts relates to the subject of science and ones’ ability to understand how scientific research is carried out and the kind of knowledge science produces. The second of Roberts’ visions relates to ones’ ability to make sense of and take part in the decision-making process regarding socio-scientific issues encountered in everyday life. Sadler (2011) further emphasises the importance of scientific literacy as the ability to negotiate issues that involve science content.

Yacoubian and BouJaoude (2010) assert that an important component of scientific literacy includes an understanding of the nature of scientific endeavour, its spirit and character. Harlen (2012) contends that scientific literacy is not related to whether a child can read and write about science, or whether they can understand scientific language, rather it is whether the child is well-educated and well-informed in science. More recently, the PISA Framework (OECD 2013) defines scientific literacy as: ‘the ability to engage with science-related issues and with the ideas of science, as a reflective citizen’ (OECD, p. 7). It also highlights the importance of science education in supporting children to become ‘informed critical consumers of scientific knowledge’, a competency that they will need as a citizen of the twenty-first century (OECD 2013, p. 5). If children are to understand socio-scientific issues, they need to develop their ability to evaluate, critique and respond to data presented as ‘scientific evidence’ in the media. They also need to have an understanding about what scientific knowledge is relevant, the reliability of the knowledge provided, how the knowledge was derived and the limitations of the knowledge (OECD 2013; Sadler 2011). Supporting children in developing more robust conceptions about NoS could provide them with the requisite knowledge and skills to support them in making sense of the range of controversial socio-scientific issues that confront society today.

For over two decades, IBSE pedagogy has been considered highly effective in supporting the development of scientific content knowledge and skills and for motivating children in science class (Artigue et al. 2012; Harlen 2010; Rocard et al. 2007). While there is no universal definition of IBSE, the term inquiry generally refers to an act of building and testing knowledge. Linn et al. (2004) define inquiry as ‘the intentional process of diagnosing problems, critiquing experiments and distinguishing alternatives, planning investigations, research conjectures, searching for information, constructing models, debating with peers and forming coherent arguments’ (p. 16). Artigue et al. (2012) describe inquiry as ‘a process that requires the active role of the pupil where learning science starts with questions rather than answers, drawing on what is already known, and then going beyond it’ (p. 4). Harlen (2010) emphasises that there is more to inquiry than merely doing hands-on activities in science class. She argues that:

Inquiry, well executed, leads to understanding and makes provision for regular reflection on what has been learned, so that new ideas are seen to be developed from earlier ones. It also involves pupils working in a way similar to that of scientists, developing their understanding by collecting and using evidence to test ways of explaining the phenomena they are studying (Harlen, 2010, p. 3).

The differences between inquiries *in* science and inquiries *about* science have been outlined by Abd-El-Khalick and Akerson (2004). They describe an inquiry *in* science as ‘an instructional approach intended to help pupils develop understandings of science content’ and an inquiry *about* science as ‘inquiry as an instructional outcome’ (p. 398). Abd-El-Khalick and Akerson assert that children’s engagement in both types of scientific inquiry during school science supports the development of more sophisticated conceptions about NoS. Frequently, the term NoS is utilised when considering matters *about* science. NoS relates to issues regarding the epistemology of science, namely, what science is, how it works, how scientists work as a social group and how science influences and is influenced by society (Lederman 1992).

While it is widely accepted amongst the science education community that learning about NoS is important, there is considerable debate regarding what exactly children should learn about NoS. On one side of this debate, there are those who argue that there are certain general characteristics or features of NoS that can be taught effectively in school contexts and there are aspects about NoS that pupils can understand. These aspects include an understanding that:

- Science is a reliable body of knowledge that provides information and explanations about the world. This *scientific* knowledge is based on evidence, is testable, developmental, constantly changing and provides new information about the world.
- There is no one universal scientific method to which all scientists rigidly adhere.
- Science is a human activity encompassing subjectivity, creativity and imagination. People of different race, nationality and gender all engage in the scientific enterprise.
- Science and society have impacted scientific development in the past and science and society are influenced and affected by one another in contemporary society (Akerson and Donnelly 2012; Akerson and Hanuscin 2007; Akerson et al. 2013; Lederman 1992; Mc Comas et al. 1998).

Kampourakis (2016) refers to this broader conceptualisation of NoS as the ‘general aspects’ account of NoS. Advocates of the ‘general aspects’ account of NoS assert that this

conceptualisation addresses common misconceptions children hold regarding NoS, rather than addressing all aspects of the multifaceted nature of the different scientific disciplines.

Abd-El-Khalick (2012b) proposes a framework for teaching about NoS that continues to focus on the ‘general aspects’ of NoS but where engagement with these aspects is addressed at increasing levels of complexity as students progress from primary through third-level education programmes. He suggests that such an approach to learning about NoS would involve students engaging with NoS content at different levels, spanning across a continuum from a more general unproblematic articulation of NoS for young children towards increasingly more complex or controversial aspects that would acknowledge students’ developmental levels (Abd-El-Khalick 2012b, p. 69). Such an approach, he argues, would be in keeping with current approaches to the way in which scientific content knowledge is addressed in different science curricula. Abd-El-Khalick (2012b) asserts that this framework would facilitate teachers in supporting their students’ learning about NoS and would enable teachers to tailor NoS content to align with students’ abilities.

Akerson et al. (2013) also assert that such concrete NoS aspects that are included in the ‘general aspects’ conceptualisation are more readily attainable for primary school children. They contend that the ‘general aspects’ conceptualisation of NoS should be introduced to young children in the first instance and that they should then gradually be introduced to the more abstract natures of the different sciences. There is much empirical evidence that indicates that the ‘general aspects’ account of NoS is an effective introduction to teaching and learning about NoS and it is also evident that affording children experiences that explicitly address the ‘general aspects’ of NoS can positively influence their views of NoS (Akerson and Hanuscin 2007; Akerson and Volrich 2006; Khishfe and Abd-El-Khalick 2002). Furthermore, the research has shown that children with good understanding of the ‘general aspects’ of NoS develop better understanding of scientific concepts and scientific inquiry and have more positive attitudes towards school science (Abd-El-Khalick 2012a; Lederman 2007; Lederman and Lederman 2014). Other studies, such as Driver et al. (1996) for example, revealed that children with sophisticated conceptions of the ‘general aspects’ of NoS develop more ‘dynamic views’ of science, that is they have a better understanding of the tentative nature of scientific knowledge and inquiry in contrast to more ‘static views’, perceiving science as a group of facts to be memorised.

A recent Irish study (Murphy et al. 2011) found that explicit reflective approaches to teaching about ‘general aspects’ of NoS provided an essential link to making school science more ‘relevant’ for children and helped children see how school science related to scientific inquiry. This study found that children who engaged with activities about NoS revealed a more in-depth and elaborate articulation of scientific processes. The authors asserted that there is *added value* in engaging children with activities about NoS as part of the science curriculum as these experiences appear to help young children make sense of science and scientific processes which in turn improve their attitudes towards science (Murphy et al. 2011). Others have found that children who leave school with good conceptions of the ‘general aspects’ of NoS had greater interest in science and developed a greater appreciation of science’s role in contemporary society and a better understanding of socio-scientific issues (Driver et al. 1996; Khishfe 2012; Lederman et al. 2013).

However, there are many critiques of the ‘general aspects’ conceptualisation of NoS. Clough (2006) suggests that the different aspects or ‘tenets’ of NoS outlined in the ‘general aspects’ conceptualisation should be included in science classes as questions. This he argues would prevent teachers thinking that the list of ‘tenets’ need to be transmitted to children. Irzik

and Nola (2014) argue that the ‘general aspects’ conceptualisation of NoS does not account for the variations across the different scientific disciplines. They put forward a family resemblance approach (FRA) to learning about NoS, which they argue addresses the complex nature of sciences. Irzik and Nola’s FRA acknowledges that while there is a resemblance between the different scientific disciplines, they are not all the same. Therefore, there is a need to have different accounts of the different nature of sciences. They do argue, however, that there are sufficient similarities between the different scientific disciplines to be characterised as science (Irzik and Nola 2014).

Erduran and Dagher (2014a) further develop Irzik and Nola’s FRA into a pedagogical model for including NoS content in science pedagogy. Their ‘FRA wheel’ model depicts the relationship between science as a cognitive epistemic system and science as a social institution system. They represent the multifaceted NoS as a ‘FRA wheel’ that symbolises the complexity of science, comprising multiple components (including aims and values, methods, knowledge, practices, social values, scientific ethos, financial systems, political power structures, social organisations and interactions) whereby these different components constantly interact with one another (Erduran and Dagher 2014a). While the ‘FRA wheel’ framework acknowledges the different scientific disciplines, it also highlights the interdisciplinary components of science. Erduran and Dagher provide concrete examples of how the ‘FRA wheel’ can be used to contextualise science concepts and related NoS components within school science and argue that when NoS content is approached using the ‘FRA wheel’ in science education, students learn about NoS in a more authentic and coherent way (Erduran and Dagher 2014a, b).

Van Dijk (2011) acknowledges that teaching about ‘general aspects’ of NoS is effective in addressing children’s preconceptions about NoS. However, she argues that children should also be provided with opportunities to learn about the different ‘natures of sciences’ and should explore the similarities and differences between the different scientific disciplines. Matthews (2012) is also critical of the list of ‘tenets’ of NoS in the ‘general aspects’ of NoS account as he fears that children would see that as another list to be learned off. He claims that children should learn about NoS from a more historical and philosophical perspective where they are afforded opportunities to reflect on, and analyse different aspects of NoS to develop their own conceptualisations about science.

Ryder and Martins (2015) argue that from a philosophical perspective science is too complex to be defined as a list of characteristics and believe that the ‘general aspects’ account of NoS does not consider the processes of science in sufficient depth. They acknowledge, however, that from a pragmatic perspective such a set of characteristics outlined in the ‘general aspects’ account is useful as a set of learning outcomes about science that can be included in science curricula. Ryder and Martins advise that the more general conceptualisation of NoS should not be dismissed or overlooked but that caution should be taken with certain statements about NoS, and they emphasise the importance of the role of continuing professional development in developing more current views about science.

After a careful consideration of the different arguments for and against the ‘general aspects’ conceptualisation of NoS, more recently, Kampourakis (2016) concludes that the ‘general aspects’ of NoS is an effective entry point towards the development of contemporary conceptions of NoS and is effective in addressing children’s preconceptions regarding NoS. He proposes that once the myths pupils hold about NoS have been addressed, pupils would then be in a position to engage with a more in-depth exploration of the multifaceted nature of the different scientific disciplines. Kampourakis stated that the development of NoS conceptions could be addressed along a three-stage continuum:

- Stage 1. —Introduction to the general aspects of NoS where pupils' myths about NoS are addressed
- Stage 2. —Exploration of the general aspects of NoS within different scientific disciplines
- Stage 3. —Exploration of the diversity of the different scientific disciplines

Kampourakis does conclude, however, that further research is required to establish whether the 'general aspects' and the FRA conceptualisations of NoS can be linked in an effective and meaningful way along the same learning continuum (Kampourakis 2016, p. 679).

It is well documented that effective professional development is a key factor in developing primary and post-primary teachers' PCK in NoS and scientific inquiry. However, there appears to be a dearth of research that explores whether primary teachers' participation in targeted continuing professional development can positively affect both children's experiences of scientific inquiry and learning about NoS. There is also little research that explores primary school children's understanding of general aspects of NoS. This research is revealing in these regards.

Methodology

Conceptual Framework for Continuing Professional Development

The conceptual framework for the targeted scientific inquiry/NoS programme was based on Desimone's (2009) core conceptual framework (Fig. 1) for studying the effects of professional development on teachers and children.

Desimone's framework connects core features of professional development with increased teacher knowledge, changes in instruction and improved children's achievement. The conceptual framework (p. 184) involves four steps:

1. Teachers participate in effective professional development—set of five core features.
2. The professional development increases teachers' knowledge and skills and/or changes their attitudes and beliefs.
3. Teachers use their new knowledge and skills, attitudes and beliefs to improve the content of their instruction or their approach to pedagogy or both.

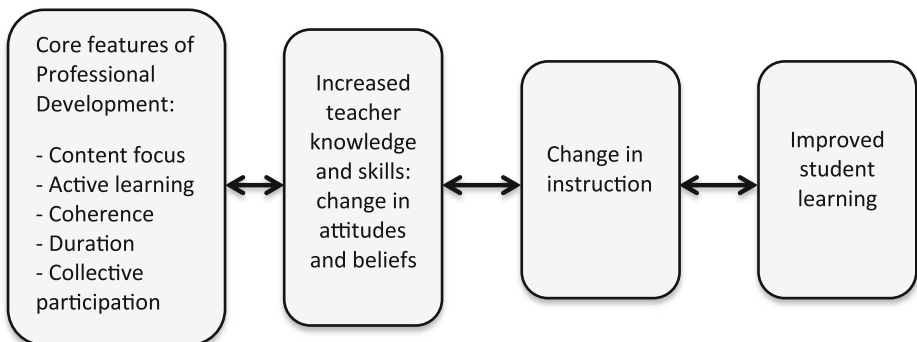


Fig. 1 Desimone's core conceptual framework

4. The instructional changes promote increased pupil learning.

Most importantly, the framework considers the influence of professional development on teacher change and pupil improvement, both of which are required to improve our understanding of how professional development works. The second phase of this study, reported in this paper, set out to investigate the influence of a professional development programme on the final step of Desimone’s core conceptual framework—improved pupil learning.

Theoretical Framework and Content of the Professional Development Programme

The main aim of the 2-year professional development programme was to support the participating teachers in developing their PCK in NoS embedded scientific inquiry to bring about progressive changes to the teaching and learning of primary science in Irish primary classrooms. The study was carried out in 10 primary schools in the Dublin urban area. The participating teachers all taught classes in the upper primary age range (age 8 to 12 years). Prior to participating in the professional development programme, the 17 primary school teachers had little if any experience of implementing inquiry-based approaches to science, none of the teachers had heard about NoS and all of them held misconceptions regarding general aspects of NoS (Murphy et al. 2015). This 2-year professional development programme, therefore, was developed to introduce these teachers to NoS and IBSE pedagogies that were deemed appropriate to implement as part of the Irish primary science curriculum. Figure 2 provides an overview of the theoretical framework that informed the content of the professional programme.

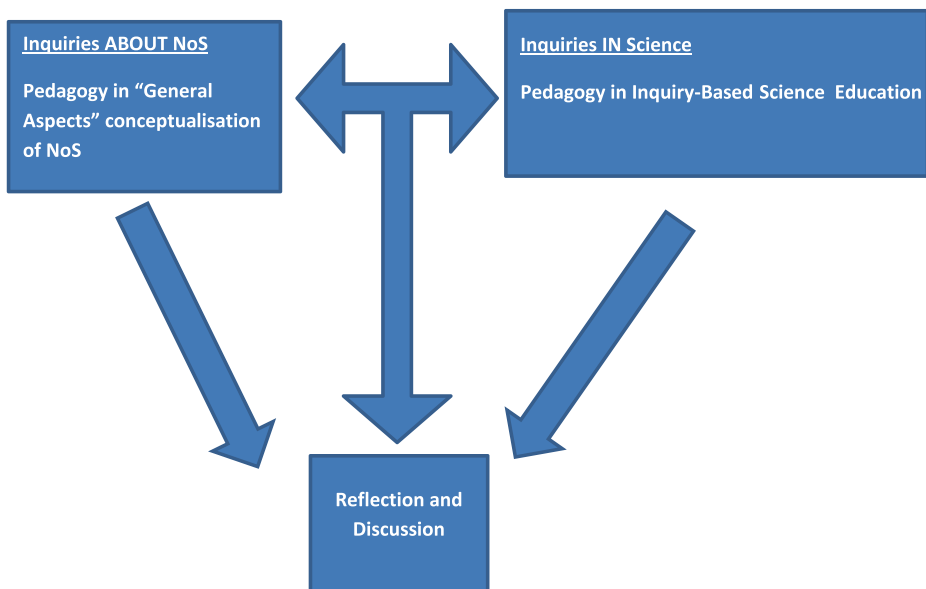


Fig. 2 Theoretical framework that informed the content of the professional development programme

Inquiries *About* NoS

To support teachers in developing their PCK in teaching *about* NoS, they were afforded frequent opportunities to engage with, reflect on and implement inquiries that explicitly addressed aspects *about* NoS. These inquiries *about* NoS included tasks that did not necessarily focus on scientific content, rather, they focussed on particular aspects *about* NoS. As this was an introduction to NoS pedagogy, the aspects *about* NoS that were addressed in the professional development programme were based around the ‘general aspects’ conceptualisation of NoS. The ‘general aspects’ of NoS that were addressed included

- Science as a reliable body of knowledge that is based on evidence, is testable, developmental and provides new information about the world.
- There is no universal scientific method to which all scientists rigidly adhere. Although scientific inquiry involves questioning, planning and carrying out investigations, collecting, analysing and interpreting evidence, constructing models, discussing and debating findings with other scientists, in reality, there is no single universal method for ‘doing science’.
- Science is a human activity encompassing subjectivity, creativity and imagination.
- Science and society have impacted scientific development in the past and science and society are influenced and affected by one another in society today (Akerson and Hanuscin 2007; Lederman 1992; Mc Comas et al. 1998).

The *Tricky Tracks*, the *Tube*, the *Cube* activities (Abd-El-Khalick et al. 1998) and the *Mysterious Bucket* (Pearson 2009) are examples of the type of inquiries *about* ‘general aspects’ of NoS that the teachers were introduced to, engaged with, reflected on and implemented in their classrooms during the programme. These inquiries enabled the teachers to familiarise themselves with the ‘general aspects’ of NoS and which, in turn, enabled them to recognise and explore NoS embedded in inquiries *in* science.

Inquiries *in* Science

Inquiries *in* science included inquiries that had a scientific context and were explicitly aimed at supporting the development of children’s scientific knowledge and scientific inquiry (process) skills while engaging in school science. The content of the inquiries *in* science in the professional development programme was based on the different strands of the primary science curriculum, namely Living Things, Energy and Forces, Materials and Environmental Awareness and Care (DES 1999).

The professional development programme provided teachers with opportunities to engage with, reflect on and implement different teaching methodologies that were grounded within a social constructivist framework. These included teacher-directed and child-led investigations, activities designed to provide children with opportunities to develop particular science skills, using digital technologies in science class and strategies for formative and summative assessment. The inquiry-based methodologies that were modelled in the workshops and subsequently adopted by the teachers in their classrooms were based on Harlen’s (2012a) Framework for Inquiry, as this framework was very closely aligned with the social constructivist pedagogies underpinning the Irish Primary Science Curriculum (DES 1999). Thus, the professional development programme

supported the assumption that teachers benefit from inquiry experiences that are grounded in the same pedagogical principles that they are expected to implement with their own pupils (Loucks-Horsley et al. 2003).

Examples of some of the inquiries *in* science the teachers taught about included inquiries related to insulation (heat and sound), sound travelling through different mediums, heat transfer, friction and air resistance, magnetism and electricity, properties of materials, materials and change, the digestive and respiratory systems and germination and plant growth.

Reflection and Discussion

A core feature of implementing inquiries *about* and *in* science was that teachers would afford their pupils frequent opportunities for discussion and reflection. As the teachers were new to both types of inquiries, they were encouraged to intentionally plan to afford their pupils opportunities for explicit reflection and discussion on different aspects of NoS and on their engagement with scientific inquiries throughout every lesson. Research has shown that explicit reflective instruction is fundamental to developing pupils' understanding of NoS (Khishfe 2012; Khishfe and Lederman 2007). Teachers in the current programme were encouraged to draw their pupils' attention to how they were working like 'real' scientists while they were doing their inquiries *in* science and applying different inquiry (process) skills. This further supported their pupils' developing conceptions *about* NoS through scientific inquiries. So, for example, when carrying out an investigation as to whether the heat of a ball affected the height at which it bounced, the teacher might ask the children to discuss their observations and inferences and to reflect on how they were working like scientists while making observations/inferences about the 'bouncy ball' investigation. Similar to studies such as Driver et al. (1996), Akerson and Hanuscin (2007) and Akerson et al. (2013), the authors were of the opinion that opportunities afforded to children to apply, develop and reflect on 'general aspects of NoS' *and* scientific processes while engaging in scientific inquiries in school would support children developing more robust conceptions of 'general aspects' of NoS. Furthermore, Deng et al. (2011) concluded, through an extensive review of the literature, that the most effective way to improve pupils' conceptions of NoS across all grade levels was through inquiry-orientated science that explicitly taught NoS embedded in the content of school science.

Implementation of Professional Development Programme

As mentioned earlier, all of the professional development methodologies were grounded within a social constructivist framework. Hands-on activities, group work, discussion and reflection were a core feature of both the inquiries *in* and *about* science. The researchers worked closely with the teachers to support them in planning different units of work. In order to implement the professional development methodologies in their classes, the teachers first referred to the Primary Science Curriculum (DES 1999) to see which strands (Living Things, Energy and Forces, Materials, Environmental Awareness and Care) they wanted to teach in a given month. They then planned the different inquiries *in* science with which they wished their pupils to engage in the unit. Many of these inquiries *in* science were those the teachers had encountered during the professional development workshops. However, the teachers also developed other scientific inquiries

that were based on the professional development methodologies and Harlen's (2012a) framework for inquiry. Once the scientific inquiries were planned, the teachers then selected which 'general aspects' of NoS they wished to explicitly address in the unit. They selected one or two of the inquiries *about* science they had done in the professional development programme. The teachers were encouraged to start the unit of work with the inquiries *about* science and afford the children opportunities to reflect on and discuss the particular aspect(s) of NoS. Then, when the children were carrying out the inquiries, related to the content and skills of the science curriculum, the teacher again encouraged the children to reflect on the particular general aspect(s) of NoS that had been addressed at the beginning of the unit of work. This approach is similar to Akerson and Hanuscin (2007) study whereby teachers (primary and kindergarten) embedded the aspects of NoS within scientific inquiry lessons. An example of the inquiry-based approach the teachers engaged with during a workshop was as follows. The teachers watched and discussed a number of advertisements on kitchen paper towels, each claiming to be the 'best' brand. After the discussion, the teachers were given a number of different brands and asked to investigate the question: 'Which kitchen paper towel is the best?' The teachers, working in small groups, initially had to define what they perceived to be the 'best' (for example, was it the cheapest? most absorbent? most durable?). Once each group had elaborated their definition of 'best', they then planned and carried out a fair test investigation to determine which was the 'best' paper towel. The teachers analysed their data, formulated a conclusion and reported their findings to the whole class group. The workshop concluded with a discussion on the aspects of NoS that were embedded in the scientific inquiry. For example, a discussion on the nature of scientific inquiry followed, where teachers explored whether the results may have been different if they had conducted the fair test in a different way to another group or a discussion of what they inferred from different observations they had made throughout the investigations. Debriefing the NoS aspects of investigations in this manner helped model how NoS could be made explicit to their pupils during an inquiry lesson.

Throughout the programme, explicit links were drawn as to how the inquiry-based science and NoS pedagogies that were introduced on the programme were relevant to the content and methodologies underpinning the Irish Primary Science Curriculum (DES 1999). As recommended by Clough (2006), the researchers acknowledged that it was imperative that the teachers understood that the professional development methodologies were not additional methodologies and content that teachers had to teach, rather they were methodologies and content that were relevant to the Irish primary science curriculum.

Sampling

Schools that reflected different types in the Irish Primary School system were approached to participate in the project. Ultimately, 17 teachers from 10 Dublin urban schools elected to participate in this 2-year professional development programme.

The 17 teachers represented a range of backgrounds in terms of how long they had been teaching, their qualifications in science and science education professional development courses they had previously attended. Throughout the second year of the programme, 17 classes, totalling 459 children, aged between 6 and 12 years (2nd to 6th class) were taught science by the 17 participating teachers.

Data Collection and Analysis

During the second year of the professional development programme, a concurrent mixed-methods design was chosen to examine whether the teachers' participation in the professional development positively affected children's learning. To this end, data from the children were gathered via questionnaires and group interviews.

Children's Questionnaires

The questionnaire was developed following consultation of relevant literature (Campbell et al. 2008; Lederman et al. 2002) for use in an Irish context. The questionnaire contained 26 five-point (smiley face) Likert scale format attitudinal statements that were grouped in two categories. Of these statements, 14 related to the children's experiences of scientific inquiry and were adapted from Campbell et al. (2008). The remaining 12 statements related to 'general aspects' of NoS (namely the nature of scientific knowledge, nature of scientific inquiry, science as a human activity). These questions were adapted from Lederman et al. (2002). The children were asked to indicate to what extent they agreed or disagreed with each statement. Analysis of grouped items gave Cronbach's alpha values of 0.7 or higher, indicating a high level of reliability (Pallant 2016; Tabachnick and Fidell 2013). The face and content validity of the questionnaire was validated through piloting, where the questionnaire was distributed to a sample of 10 primary school children (ages ranging from 9 to 12 years old); minor revisions were made following the pilot.

The questionnaire was administered during the second year of the professional development programme, at the beginning of the school year, prior to the children's first science lesson and at the end of the school year (Appendix 1). Upon analysis, 'data reduction' was completed whereby all the questionnaires were examined for completeness, accuracy and uniformity of questions answered (Moser and Kalton 1977). All data were coded and entered into Statistical Package for Social Sciences (SPSS) (version 23) for further analysis. Descriptive statistics were used to clean the data, check for missing data and outliers and determine a general profile for each question (Pallant 2016). The Likert scale coding was considered ordinal, and using Connolly's (2007) summary guide for selecting appropriate statistical tests, a non-parametric test, a Wilcoxon signed rank test, was chosen as the most appropriate for comparing results in the initial and exit questionnaires.

Group Interviews

Concurrently, semi-structured group interviews were conducted with children from one class in each of the 10 schools at the beginning and end of the school year. This facilitated a more in-depth investigation into the children's experiences of scientific inquiry in school and conceptions of 'general aspects' of NoS. Each interview followed a protocol, was piloted with four children (ages 8, 9, 11 and 12) from another urban Dublin school and revised by the research group as a whole (Appendix 2). Member-checking was used to improve the accuracy, validity and transferability of the interview protocol and corresponding responses. The class teachers chose the four children to be interviewed but were asked to ensure there was a range of ability amongst the children they selected for interview. The interviews were recorded and transcribed.

A phenomenological mode of inquiry was chosen to analyse the pre- and post-interview data (Goetz and Lecompte 1984). Phenomenological research uses the analysis of significant statements, the generation of meaning and the development of description (Moustakas 1994). The interview transcripts were read and re-read prior to coding. These data were unitised, that is, units of information served as the basis for defining a significant statement (Glaser and Strauss 1967), with each unit providing evidence of children’s experience of scientific inquiry and understanding of NoS, e.g. *the tentative nature of science*. Units which appeared to have similar content were then categorised, with each category representing a distinct theme (Cohen et al. 2011). The data were then re-read, attentive to the themes previously highlighted to determine if more evidence could support each theme or identify the need for additional information (Creswell 2014). This method of constant comparison revealed a number of themes, for example, traditional, inductive approaches to teaching science; collaboration; child-led investigations; tentative NoS; science as a human endeavour; etc. These themes will be discussed in more detail in the “Findings” section. Three researchers coded the interview data and the overall inter-rater reliability pertaining to the categorisation of the units was 0.96, adding to the accuracy of the qualitative findings (Creswell 2014).

The concurrent, mixed design integrated the quantitative and qualitative data during the analysis stage. The integration of the questionnaire and interview data, independent data sets, improved the accuracy of the findings (Burke-Johnson et al. 2007). It allowed for cross-validation where two or more methods are found to yield congruent or comparable data (Jick 1979). Additionally, triangulation enriched our understanding of children’s experiences of scientific inquiry and conceptions of NoS, allowing a deeper dimension of the findings to emerge. Thus, the use of between-methods, methodological triangulation added to the validity of the findings (Burke-Johnson et al. 2007; Sieber 1973).

While the researchers had a strong influence on teachers’ developing PCK in NoS, through scientific inquiry during the professional development programme, they did not have a direct influence on children’s experiences of school science or on children’s learning. However, when gathering data from the children, the researchers were aware of potential biases including interviewee’s eagerness to please the researcher or the tendency of the researchers to look for answers that were supportive of their personal conceptions or agendas and made every effort to eliminate them. To this extent, an interview schedule was developed and adhered. To reduce the possibility of the ‘Hawthorne effect’ (Robson 2002), as suggested by Briggs (1986), before the questionnaires were administered and interviews conducted, the children were reminded that there were no ‘right’ or ‘wrong’ answers and that it was ‘their ideas’ that were important. The teachers interviewed in the first phase of this study (Murphy et al. 2015) confirmed that no other event, during the course of the professional development programme, may have affected the children’s experience of scientific inquiry and/or understanding of NoS; thus, validity threats of ‘history’ and ‘maturation’ were reduced (Creswell 2014). Additionally, given that there was 10 months between administration of the pre- and post-questionnaire, children were unlikely to have become ‘test-wise’ (Creswell 2014). The triangulation of the questionnaire data and the interview data during the analysis stage of this study further added to the validity of the findings.

Ethical Considerations

At the outset, the children were given a letter seeking parental/guardian consent to complete the questionnaires and participate in the interviews. The letters informed the guardians of the

purpose and nature of the research and assured confidentiality. The children were also informed about the purpose of the questionnaires and group interviews and were given the option to fill in the questionnaires. Participation in the interviews was also voluntary. The questions the children were asked in the questionnaires and group interviews were unobtrusive and did not require them to divulge any personal information. Nevertheless, the children were given assurances of anonymity and the personal identities of the participants were not revealed at any stage.

Findings

Children's Experiences of Scientific Inquiry During School Science

Two identical questionnaires were administered to the children at the beginning and end of the second year of the programme. The questionnaire consisted of 26 Likert-type attitudinal statements, of which 12 related to NoS aspects and 14 related to experiences of scientific inquiry in school (Appendix 1). Out of the 14 statements relating to children's experiences of scientific inquiry in school, 11 related specifically to child-led inquiry-based approaches to science and three related to more traditional inductive, teacher-led approaches to learning science. The analysis of the children's responses (pre- and post-intervention) to the 11 questions relating to their experiences of child-led scientific inquiry in school is presented in Table 1.

At the exit stage, a Wilcoxon signed rank test indicated that the number of children who agreed or agreed strongly with eight out of these 11 statements in the exit questionnaire was significantly higher than the initial questionnaire ($P < 0.001$). Further, Cohen's effect size value revealed a small to moderate practical significance, suggesting that these children were engaging more frequently with inquiry-based methodologies in school at the end of the school year (Table 1). Conversely, a Wilcoxon signed rank test revealed that there was a statistically significant increase ($P < 0.001$) in the number of children who disagreed or disagreed strongly with the three statements relating to more teacher-led methodologies at the exit stage, with Cohen's effect size revealing a small to moderate significance (Table 2). This implies that by the end of the year, these children's experiences of school science were less teacher-led and more inquiry-based.

The interview data revealed similar findings and indicated that at the exit stage the children were engaging more frequently with more child-led inquiries during school science. The interview data were analysed using the constant comparative method (Glaser and Strauss 1967) and five categories relating to children's experiences of school science emerged. Table 3 provides a brief description of these five categories and exemplars of typical responses in each category at the initial and exit stages.

It is evident from Table 3 that in the initial interviews, the children's responses tended to relate to more teacher-led methodologies. Children spoke about following teachers' step by step instructions when doing experiments, watching teacher demonstrations, listening to teacher explanations, completing worksheets and writing things down from the white board. Many children expressed their dislike of such methods often citing words such as 'hate', 'unfair' and 'boring' when describing such teacher-led lessons. This is similar to the findings from another Irish study that highlighted concerns over the frequency of teacher-led, closed science lessons in Irish primary classrooms (Varley et al. 2008). However, at the exit stage, all

Table 1 Analysis of children's responses to their experiences of child-led scientific inquiries

Question	Initial	Exit	Difference between means	<i>r</i>	<i>z</i>	Effect size
	Pre Mean (SD) <i>N</i> = 459	Post Mean (SD) <i>N</i> = 459				
We talk about whether we are carrying out a fair test*	3.69 (1.40)	4.42 (0.74)	0.73+	0.35	10.50	Medium
In school, we record what happens when we are doing investigations*	3.91 (1.24)	4.46 (0.78)	0.55+	0.25	7.70	Medium
In class, we carry out science investigations ourselves*	3.05 (1.25)	3.48 (1.34)	0.43+	0.15	4.43	Small
In class, we plan how we are going to carry out science investigations ourselves*	3.97 (0.95)	4.24 (0.83)	0.27+	0.15	4.33	Small
In school, we work in groups when we are doing science investigations*	4.3 (0.93)	4.53 (0.71)	0.23+	0.14	4.24	Small
We record the results of our investigations in different ways*	3.76 (1.16)	4.04 (1.01)	0.28+	0.12	3.47	Small
We make predictions before we carry out science investigations*	4.18 (0.90)	4.53 (0.80)	0.17+	0.12	3.53	Small
We discuss results of our investigations in science class*	4.21 (0.93)	4.42 (0.69)	0.21+	0.12	3.44	Small
We get the chance to ask questions in science class	4.3 (0.86)	4.36 (0.74)	0.06+	0.05	1.52	Small
In class, we talk about science in our everyday lives	3.58 (1.23)	3.75 (1.08)	0.17+	0.04	1.27	0
We ask questions when we are doing science investigations in class	4.21 (0.91)	4.23 (0.86)	0.02+	0.01	0.22	0

of the children in the focus groups provided accounts of school science that depicted more inquiry-based methodologies where children 'planned investigations themselves', 'worked in groups' and that 'each group didn't always do their investigations in the same way but that this was ok as long as they conducted fair test'. In comparison, there were very few references to more teacher-led approaches to science in the exit interviews.

The number of times the children referred to activities relating to each of the five categories in the initial and exit interviews was counted. Table 4 provides a breakdown of the number of references the children made to each of the categories at the initial and exit stages.

Table 2 Analysis of pupils' responses to their experiences of teacher-led methodologies

Question	Initial	Exit	Difference between means	<i>r</i>	<i>z</i>	Effect size
	Pre Mean (SD) <i>N</i> = 459	Post Mean (SD) <i>N</i> = 459				
My teacher tells us exactly how we should do an experiment*	3.61 (1.14)	2.73 (1.43)	0.88–	0.32	9.52	Medium
In class, my teacher usually does the investigations*	2.41 (1.25)	1.83 (1.08)	0.58–	0.24	7.08	Small
During science class, we always take notes down from the board that the teacher gives	3.62 (1.17)	3.12 (1.28)	0.50–	0.19	5.58	Small

Table 3 Children’s experiences of scientific inquiry: category descriptors and examples of responses in the initial and exit interviews

Category title and descriptor	Example of children’s responses Initial interviews	Example of children’s responses Exit interviews
1. Completion of worksheets/workbooks/-writing instructions (not recording)	<p>“... we had to do these sheets but nobody got them right because we had to mention everything and we always got them for homework because we could not get them right”</p> <p>“We write a demonstration and instructions in our copy and draw pictures of the science”</p>	<p>“I like it (this year) because I think it was last year or the year before, they used to write up on the board what to do and then we had to write it down and then we would get to do it. But this, we just em, we do not write it down or anything. We just experiment with ourselves. So we do a lot more of it”</p>
2. Teacher doing science activities with class observing	<p>“The teacher sets it up and he gets, one boy to do it and then everyone has to sit down and just, like, look at it”</p> <p>“I’d like ... if a good lot of people were doing something because it’s mainly the teacher who would pour stuff into another and sometimes it spoils it – you are just sitting watching”</p>	<p>“It is not really science for us where (teacher) is doing it all and we are just watching”</p>
3. Hands on activities but prescribed by teacher	<p>“Well, once, we made paper cup telephones. We made a hole in the middle of them and string through and tied a knot in the middle of the cup. Then we put one of them up to your ear and another person spoke to you” (initial interview)</p> <p>“We mixed vinegar and baking soda and it exploded”</p>	
4. Teacher explaining facts	<p>“I’d probably see ... a teacher standing in front of the board, pointing out stuff. And drawing explanations about it”</p>	
5. Child-led investigation		<p>“We write down our predictions when we are doing science and, em, we test them and then we find out the answer. And, say, the parachutes we did in class, we would write down which one would you think, which type of parachute would stay up the longest. And we found out”</p> <p>“But I like it (science) even more now because we usually use our minds and everything, instead of like, writing stuff down that the teacher gave us. ‘Cause ... this time we can think about it and do it our own way”</p> <p>“Like, once we had to do a bubble investigation to find out which made the biggest bubbles and how to make the ... the most bubbles, the smallest bubble, the long-lasting bubble – we had to do it ourselves ... different groups did different investigations ... we had to make sure it was fair ...”</p> <p>“Like to test jelly or something and Miss Reynolds knows what we have to do but she will not tell us. So, we have to come up with our own idea and try it and test it and figure out how we test our experiment”</p>

Table 4 The number of references children’s made in each of the experiences of scientific inquiry categories in the initial and exit interviews

Teaching approaches	Initial focus group interviews	Exit focus group interviews
	Number of references	Number of references
1. Completion of worksheets/workbooks (not recording)	12	0
2. Teacher doing science activities with class observing	7	1
3. Teacher explaining things on the black board	3	0
4. Teacher-led investigation	66	5
5. Child-led investigations	1	38

Table 4 illustrates that at the exit stage there was a notable increase in the number of responses the children made with regard to being provided with opportunities to explore their own inquiry questions and to plan and carry out their own investigations (from 1 to 47) with a corresponding decrease in the number of responses that related to more teacher-led methodologies (from 66 to 5).

It is apparent from both the questionnaire and interview data that the children were engaging more frequently with inquiry-based methodologies and less frequently with more teacher-led approaches at the end of the school year. It is also important to note that the inquiry activities to which the children referred in the exit interviews were almost exclusively inquiries that their teachers had engaged with, or planned during the professional development programme (for example, parachute, insulation, jelly and best bubble investigations, Table 3). The evidence, therefore, suggests that teachers were utilising the professional development inquiry-based methodologies and it would appear that they could effectively translate these methodologies into their classroom practice, which positively affected the children’s experiences of engaging with scientific inquiry in school.

Children’s Conceptions About General Aspects of NoS

The questionnaire contained 12 Likert-type attitudinal statements regarding NoS, 10 of which referred to ‘general aspects’ of NoS and two that did not. Table 5 presents the children’s responses to the 12 in the initial and exit questionnaires.

In the exit questionnaire, there was an increase in the number of pupils who agreed/strongly agreed with 10 items relating to ‘general aspects’ of NoS. A Wilcoxon signed rank test revealed that out of those 10 questions, six had a statistically significant rise ($P < 0.05$) in children’s understanding of ‘general aspects’ of NoS in the exit questionnaire, indicating a small to medium effect size using Cohen’s criteria (Table 5). While four items related to science as a human endeavour, history of science and science and society revealed an increase in the children’s understanding in the exit questionnaire, these were not statistically significant. There was a significant decrease ($P < 0.05$) in the number of children who disagreed/disagreed strongly with the two items that represented naive NoS views, with a Wilcoxon signed rank test indicating a small to medium effect size (Table 5).

These data suggest that the children were beginning to develop their understanding of different ‘general aspects’ of NoS.

Table 5 Analysis of pupils’ responses to NoS items on questionnaires

Question <i>P</i> < 0.05*	Initial	Exit	Difference between means	<i>r</i>	<i>z</i>	Effect size Cohen (1988) criteria
	Pre Mean (SD) <i>N</i> = 459	Post Mean (SD) <i>N</i> = 459				
Once a science fact is discovered, it does not change*	2.75 (1.26)	1.99 (1.13)	0.76–	0.27	8.14	Medium
Scientists use their imagination when they do experiments*	3.57 (3.57)	4.18 (0.94)	0.61+	0.25	7.45	Medium
Different scientists have different answers to the same questions*	4.07 (1.01)	4.48 (0.70)	0.41+	0.22	6.08	Small
In school, we do science activities that help us understand about science observations and inferences*	4.06 (0.94)	4.41 (0.74)	0.35+	0.20	6.08	Small
Scientists make predictions in their work *	2.86 (1.47)	3.36 (1.24)	0.50+	0.19	5.77	Small
In class, we do activities that show us how scientists use their creativity in their work*	4.06 (0.94)	4.41 (0.74)	0.35+	0.19	5.60	Small
Scientists use their opinions when they are explaining things*	3.76 (1.01)	4.1 (0.79)	0.34+	0.20	5.60	Small
Scientists usually work alone*	2.48 (1.16)	2.22 (1.00)	0.26–	0.13	3.75	Small
Scientists use their feelings and beliefs in their work	3.57 (1.20)	3.68 (1.01)	0.11+	0.05	1.44	–
Science answer questions about the world	4.08 (0.87)	4.17 (0.81)	0.09+	0.05	1.44	–
In class, we talk about science in our everyday lives	3.58 (1.23)	3.75 (1.08)	0.21+	0.04	1.266	–
It is important for people to know about famous scientists in the past	3.79 (1.08)	3.82 (0.99)	0.03+	0.02	0.63	–

Analysis of the interview data enabled a more thorough exploration of the children’s developing conceptions of ‘general aspects’ of NoS. Similar to the questionnaires, the interview data revealed that the children were developing their conceptions of science as a human activity, scientific inquiry and the tentative and developmental nature of scientific knowledge. This was particularly the case for the following ‘general aspects’ of NoS:

- Scientists make observations and inferences.
- Science is not a lone pursuit rather it involves collaboration.
- Scientists use their creativity in their work.
- There is no one scientific method.
- There is a tentative and developmental nature to scientific knowledge.

In the initial interviews when asked what kind of things scientists do, typical responses depicted ‘cartoon’ images of scientists perceiving science as a lone pursuit and scientists as not having any idea of the potential outcome of their investigations, rather that scientific inquiry comprised what Solomon et al. (1992) called ‘serendipitous empiricism’, that is a belief in ‘shot in the dark’ type approaches where scientists do not know the outcome of their experiment.

They can be mad and do crazy stuff sometimes. Well they, sometimes they make stupid experiments and it, eh, it doe stupid stuff.

A mad scientists putting together two chemicals and blowing it up

They work in a big lab and there's loads of potions

The children's responses in the initial interviews were short, did not provide examples to explain their responses, nor were any references to school science made when discussing the work of scientists. In contrast, in the exit interviews, the children's responses to this question were considerably more detailed and reflective. When asked about what kind of things scientists do, the children discussed scientists answering questions about the world, providing new knowledge about the world, carrying out investigations and inventing things. However, in particular, they talked at length about scientists making observations and inferences, making models to try to 'figure out how things work' and scientists collaborating during scientific inquiry. There were no references to these in the initial interviews.

It was apparent from the children's responses in the exit interviews that they were beginning to develop their understanding of how scientists use observations and inferences during scientific inquiry. At the exit stage, children in all focus groups referred to how scientists make observations and inferences in their work (Table 6, quote 1). When discussing scientists making inferences, it was also evident from the children's responses that they understood that scientists frequently have to make inferences, as they did not always have all the information (Table 6, quote 2). In addition the children's responses indicated that they understood that inferences were not wild guesses; rather they were informed by '*scientists' past experiences and knowledge*', indicating that the children were developing more elaborate conceptions of this aspect of NoS.

During the professional development programme, these children's teachers had engaged with a range of activities aimed at developing conceptions about the role of observations and inferences in scientific inquiry. It would appear from the children's responses that that the teachers implemented these activities in their classrooms and that the experiences teachers afforded the children to engage with and reflect on the activities were effective in developing their understanding about the differences between scientific observations and inferences. The below quote is indicative:

one set was bigger than the other ... so we said it was bigger ... that was our observation. Me and my friend we were doing it and we – she said observation and we were kind of doing an inference, because we said there was probably like a fox ... and a bird and they had a fight and then they went and talked. But we didn't exactly know what it was so - 'cause we were doing an inference instead of an observation (exit interview)

It is also worth noting that when the children were discussing how scientists use observations in their work, they provided examples from school science to explain their answers.

Another response that emerged in all of the exit group interviews in response to the question what kind of things to scientists do was that scientists make models in an attempt to explain how things work.

Suppose that a scientist has an object and they don't know what it is and they can't see inside it; they make their own model of it with creativity to see if it works the same way as the other-as the real model works. If it doesn't work they know they didn't do it right.

Table 6 Quotations from pupils in exit interviews

Observations and inferences	<p>Quote 1: “Usually they find something they cannot see inside and they have to try to work out what’s inside it. So they make observations and inferences, to make an idea of what it could be. When scientists work, they do not guess. They like, make inferences and observations.”</p> <p>Quote 2: “They find something that you cannot see inside and they have to try work out what’s inside it. So they make their observations and inferences and go to other scientists and put all their work together to make a giant idea of what it could be” (exit interview)</p> <p>Quote 3: one set was bigger than the other ... so we said it was bigger ... that was our observation. Me and my friend we were doing it and we – she said observation and we were kind of doing an inference, because we said there was probably like a fox ... and a bird and they had a fight and then they went and talked. But we did not exactly know what it was so - ‘cause we were doing an inference instead of an observation.</p> <p>Quote 4: there were four balloons that were different colours. Teacher gave one colour to every group ... and then we had to make observations and inferences about them. An observation is something that you can actually see ... And an inference is something, like, you cannot actually see ... you think it We said that ours was transparent in parts of it because you could see through it ... but also it was a bit rough on the outside and it tasted salty ... so the inference we made was that there could be salt inside of it ... we were working like scientists because they make inferences when they look at things, because they cannot always see everything ... we did not see our teacher making the ice balloons so we did not know how she made them ... we had not real proof so we had to do an inference about what was inside them</p>
Scientist make models	<p>Quote 5: “Suppose that a scientist has an object and they do not know what it is and they cannot see inside it; they make their own model of it with creativity to see if it works the same way as the other-as the real model works. If it does not work they know they did not get it right. So they make another model with the same thing, but maybe a bit more or a bit less of it” (exit interview)</p> <p>Quote 6: “She would give us a task and we’d have to try and figure out, like the magic bucket – she poured water and then blackcurrant, then Lucozade and it just came out pure water. And she said ‘What do you think – what’s stopping – why is it not coming out any different colour?’. And we all had different ideas. ... but we still do not know, we are not 100% sure” (exit interview)</p> <p>Quote 7: there was four strings coming out of it and eh, if you pulled one string from underneath ... on of the top ones would come down and if you pulled the other one on the bottom, the second one would go down and that would go up. We had to observe it first and then we had to infer what we thought was happening inside. Then we had to come up with ideas / hypothesis about what was inside the tube ... just like scientists really .. (exit interview)</p>
Collaborative NoS	<p>Quote 8: Scientists usually do not work on their own because if scientists worked on their own they’d only have one mind but if they have other people working with them for, with them, they’d have bigger ideas and more, eh, chance of getting closer to what the thing really is</p> <p>Quote 9: Sometimes they have to share information. Say that scientist would go to his scientist place and he’d go to that and say if he found bones and the other person, he’d try and get, he’d start to know a bit more about what they were</p> <p>Quote 10: ... four could work in a group ... like when we were looking at the animal bones and we did not know the animal ... we had to ask ‘Who knows that?’ and we would start getting more ideas. Like, David would give a different idea. I’d give a different idea. Conor would give another idea. So would Tom. And then we’d, like, say if it was bones, one might say ‘But that looks more like a leg’ and that’s too big to be a jaw’ and then we’d have to try and find out what leg would it be in the animal ... we had to work together to try to figure it out ... like palaeontologists if they found new bones and they were trying to figure out what animal it might be ... they’d have to share ideas ... (exit)</p>

Table 6 (continued)

Creativity in scientific inquiry	<p>Quote 11: Scientists have to use their creativity ... cos if they are trying to answer a question or find a solution to a problem they have to be creative to try to figure out how to investigate the problem ... like what kind of investigation they could do to find an answer</p> <p>Quote 12: They have to when they are making inferences cos they do not have all the information so they have to think about what they know already and what they have done already to come up with the inference ... they are being creative could you delete the space between these two quotes</p> <p>Quote 13: "I think they (scientists) do (use their creativity) ... 'because when we were doing the insulation investigation ... we had to use our creativity to find out which material would be the best insulation. We had to come up with our own way to test it, our own investigation ... to see which one was the best ... that was creative ... we were working like scientists because they have to be creative to think about how they could do an investigation" (exit interview)</p> <p>Quote 14: I think they do (scientists use their creativity) 'cause like when we were doing the phone experiment in one way you had to find out which one sounds the best. We had to use our creativity to see which material would be the best insulator. we had to come up with a way to test it. we were all given lunch boxes and we all had our phones and we had a choice of bubble wrap, a kind of a fluffy material, paper or crepe – not crepe paper, eh - Tissue paper, yeah. And eh, we had to, we could choose three of them I think it was. And we had to test each of them. We'd wrap it up and put it in the lunch box and time it to go off and then it would go off and then we'd see which one was the best Every group did it their own way and scientists go about doing investigations in different ways ... I think that's creative (exit interview)</p>
No one scientific method	<p>Quote 15: Because, like, just say, em, I – one scientist could use – just say you put jelly into water, two packets of jelly into water; another scientist might only put one. And they might have put them - they might put a second one in later on and then they would not get the same answer.</p> <p>Quote 16: "Teacher would show us the stuff we have to do the investigation ... the different groups would we'd all pick different materials 'cause we would not all be doing the same thing ... we'd be trying to figure out the answer to the question ... but in different ways ... like scientists do not always do everything the exact same"</p>
Tentative NoS	<p>Quote 17: Well, there could be some facts that might not change but there's definitely more facts that will change ... I do think that things can change though because they are always trying to improve stuff and they always go back to their old experiments and like just make them better and they do that to older stuff too. So they do that all the time.</p>

So they make another model with the same thing, but maybe a bit more or a bit less of it (exit interview)

At the exit stage, the children displayed very good understandings of how scientists make models of phenomena to see if their models behave in the same way as a particular phenomenon. They talked generally about scientists' models and then they gave examples from school science to explain their answers, again suggesting that their school experiences were effective in supporting their developing NoS conceptions. In quotes 6 and 7 (Table 6), the children are talking about two black box activities they had done in school science (The Mysterious Bucket (Pearson 2009) and the Tube (Abd-El-Khalick et al. 1998)). It is apparent from the children's responses that they were beginning to develop their understanding of how scientists make models in an attempt to explain certain scientific phenomena.

In the initial interviews, when talking about scientists working, the children never discussed how scientists work collaboratively. In fact, in every group, there were children who depicted science as a lone profession. In contrast, in every exit group interview, the children discussed how scientists collaborate during scientific inquiry (Table 6, quotes 8 and 9).

It was also apparent from every group interview at the exit stage, that the children frequently worked in groups and collaborated during school science. They were able to equate their experiences of working collaboratively during school science to scientists working collaboratively. In quote 10 (Table 6), the child is referring to a science activity their teacher had learned about during the professional development programme. The child is equating their experience of working collaboratively in science class to the work of scientists. Again the class activity appears to have been effective in developing children's understanding of the collaborative nature of scientific inquiry.

In the initial interviews, when asked whether scientists use their creativity in their work, children in all interviews said they used their creativity when they were inventing new things.

Yes, you have to be creative to be a scientist because to be a scientist you'll have to make stuff (initial interview)

When asked whether scientists use their creativity while carrying out investigations and experiments, all of the children in the initial interviews said that they did not use their creativity during scientific inquiry. They revealed naïve conceptions regarding this aspect of NoS in that their answers talked about how scientists have to follow a set of procedures in order to get the 'correct' answer, and if they used their creativity when doing their experiments, they might not get the 'right answer' and their experiments would 'go wrong'. The following quote is illustrative:

No (scientists do not use their imagination and creativity) ... because if the experiment wouldn't run right, they'd have to go by the book or, like, something like that. (initial interview)

In contrast, in the exit interviews when asked about scientists being creative, the children discussed at length how scientists use their creativity throughout their work. They talked about how scientists use their creativity when devising investigations, when interpreting findings and when making inferences (Table 6 quotes 11 and 12). Again when talking about scientists' creativity, children in all of the exit group interviews provided examples from school science to illustrate the role of creativity in scientific inquiry, equating the creativity they used in school science to that of scientists (Table 6, quotes 13 and 14). The children also rejected the existence of 'one scientific method' at the exit stage, strongly emphasising that scientists do things in different ways as a result of their creativity and different experiences.

Sometimes they get different evidence than other scientists. But a lot of the time they get the same results but they just do it different ways. (Exit interview)

Every scientist has a unique way of doing stuff. (Exit interview)

I think they examine evidence in different ways because like I said on my sheet, that like there's different scientists for different things and like, what the world means and stuff. (Exit interview)

The last child's quote is interesting in that she is beginning to think about the different scientific disciplines and how they differ from one another, suggesting that perhaps they have begun to reflect on the different nature of different scientific disciplines.

Again when talking about scientists not following 'one scientific method', the children referred to investigations they had done in school science where different groups came up with different investigations to answer the same question, again showing that their school science experiences were supporting their developing conceptions of NoS (Table 6, quotes 15 and 16).

In both the initial and exit interviews, the children discussed how scientific knowledge can change and develop. They talked about how scientists find out 'new things' about the world and, therefore, maintained that scientific knowledge is developmental. However, in the exit interviews, when talking about the tentative nature of scientific knowledge, children in all focus groups referred to scientific inquiries they had engaged with in school science when reflecting on the tentative nature of science, again equating school science with science (Table 6, quote 17). This was not the case in the initial interviews.

This child's response below illustrates their developing understanding of the tentative and developmental nature of scientific knowledge. The child is referring to an activity that their teacher had done in the professional development. It would appear from this reflection that engagement with this activity has supported the child in developing an understanding of the tentative NoS.

Yeah, I think it can change, like, over different years and stuff like that. Because they're trying to improve things all the time and like, different things in the world that they're trying to improve ... like what we done, we had loads of bones and we had to dig our hand in a little brown box and you had to discover what it was. We kept on picking new bones and we had to try and match what animal it was. And then we started going around and getting more ideas from other groups – like scientists do We learned more things from other groups and our ideas changed ... (exit interview)

While the questionnaire data did not reveal a significant increase in children's understanding about history of science, it was evident from the interview data that the children had been engaging with inquiries relating to history of science and that these inquiries appeared to have impacted on children's learning. The children often referred to figures and events from the history of science that they had engaged with in school when discussing the tentative nature of science, creativity in science and science as a human endeavour. In the exit interviews when talking about the tentative nature of science, the children frequently used examples from the history of science to articulate their understanding of the tentative NoS, as exemplified by the following extract:

Em, we done Leonardo Da Vinci's invention of the parachute. He never got to invent it but he had a drawing of it. So we all tried to reinvent the parachutes and after they were all made, they were made of different materials and all, like plastic bags and maybe some linen and all that stuff. So, then after when each group was done making their parachutes, we all stood up on a table and we all had our arms the same height so it would be a fair test and then we dropped them to see if it

would work and which was the best. And it turned out that - we watched a programme about it after – and it turns out to have an easier glide than the ones we have today (Exit interview).

While there was an increase in the number of references to science and society in the exit interviews, the children's responses regarding science and society referred to the role of science in society. This is consistent with the findings from the quantitative data. While it is not clear whether this aspect was particularly difficult for the pupils and they tended not to draw on examples of school science when discussing, it could be that this 'general aspect of NoS' required greater emphasis in the professional development programme.

It is not suggested that the children's earlier more 'simplistic' and 'naive' views of NoS have disappeared altogether; however, it would appear from both questionnaire and interview data that the children were starting to develop more elaborate conceptions of some 'general aspects' of NoS, namely science as a human activity, scientific inquiry and the tentative and developmental nature of scientific knowledge.

Limitations

It is acknowledged that the sample of children in this study is relatively small, and therefore, generalisations cannot be made. However, the schools were representative of the different types of schools in Ireland. Furthermore, the smaller sample permitted a more in-depth and detailed study of the children's conceptions which makes it more representative.

No control group was utilised so it is difficult to establish whether engagement with the explicit reflective approaches to NoS directly impacted children's NoS conceptions. Perhaps, the children would have developed more sophisticated NoS conceptions by engaging with the content and skills outlined in the curriculum. However, this is highly unlikely as other Irish studies (Murphy et al. 2011) and international studies (Khishfe and Abd-El-Khalick 2002; Lederman 2007) have found that simply engaging with scientific inquiries does not necessarily support children in developing their understanding about NoS rather NoS needs to be explicitly included as a cognitive learning outcome.

Evidence from quantitative and qualitative findings indicated that the children had difficulties developing conceptions regarding socio-scientific aspect of NoS. Although some NoS concepts were framed within a socio-scientific context during the professional development programme, it would appear that more explicit instruction regarding the use of socio-scientific issues in teaching about NoS through scientific inquiry is warranted.

Discussion

The findings from the *first phase* of this study revealed the positive effects participation in this professional development had on the participating teachers in terms of their confidence in teaching about NoS and in using more child-led inquiry-based approaches to teaching science. The teachers also reported that they felt that their participation in the professional development

programme had a positive impact on children's learning about NoS and on their experiences of scientific inquiry (Murphy et al. 2015).

It would appear from the findings from the *second* phase of the study, reported in this paper, that the primary teachers who participated in the professional development programme could effectively implement the professional development pedagogies in their classroom which resulted in their pupils:

- Engaging more frequently with inquiry-based approaches to learning science
- Developing a greater awareness of the scientific process skills they are using during school science
- Developing more elaborate conceptions of 'general aspects' of NoS
- Linking school science with science in the real world.

More Frequent Engagement with Scientific Inquiry

At the beginning of this study, it was apparent that these children's experiences of school science were dominated by inductive, teacher-led approaches. However, there was a significant increase in their engagement with more inquiry-based approaches and a significant decrease in engagement with more teacher-led methods at the end of the study. At the exit stage, the children revealed an ability to reflect on and discuss explicit incidents where they had planned, conducted and reflected on child-led investigations and where they had applied a range of scientific skills in science class. They consistently referred to the professional development activities they had engaged with when discussing their experiences of scientific inquiry in school, and it was apparent from their responses that engagement with the professional activities was supporting the children's awareness of different scientific processes they were using during school science.

One might argue that this increased engagement with and understanding of scientific inquiry would have come about regardless of whether their teachers had participated in the professional development. However, this is unlikely as at the beginning of the study their teachers reported that they rarely if ever afforded pupils opportunities to plan and carry out their own investigations; rather they typically gave them the equipment, told them how to set up an 'experiment' and told them what to observe and what to record (Murphy et al. 2015). One, therefore, could assume that if the teachers had not participated in the programme, they would have continued teaching science to these children as they had done previously. The findings indicate that this was not the case; rather the teachers effectively implemented the professional development inquiry-based methodologies which resulted in the children engaging more frequently with and developing a greater awareness of the scientific processes they were using during school science.

The Development of more Elaborative Conceptions of 'General Aspects' of NoS

The findings revealed that the children had developed more elaborate conceptions regarding 'general aspects' of NoS, at the exit stage. This was the case particularly

with regard to science as a human activity, the nature of scientific knowledge and the nature of scientific inquiry; all aspects of NoS about which their teachers had learned during the professional development programme. At the initial stage, the children's responses regarding different aspects of NoS were brief and rarely, if ever, did the children provide explanations to back up their responses. In contrast, at the exit stage, the children's responses regarding NoS were considerably more in-depth, diverse and reflective, revealing a more sophisticated understanding of 'general aspects' of NoS. The children almost exclusively referred to school science when discussing different 'general aspects' of NoS and the detail with which the children recalled the different NoS activities indicated that engagement with the activities appeared to have been instrumental in supporting their developing NoS conceptions. Furthermore, engagement with the explicit reflective approaches to learning *about* NoS also appeared to have enabled the children to develop a greater awareness of scientific process skills they were using during school science. This was apparent as when the children were reflecting on different scientific process skills they were using, they frequently referred to aspects *about* NoS in their reflections. These findings were similar to those of Khishfe and Abd-El-Khalick (2002) and Akerson and Donnelly (2012) who found that explicit approaches to teaching about NoS embedded within scientific inquiry improved primary school children's conceptions of NoS. It is important to note that all of the NoS inquiries to which the children referred were inquiries that their teachers had engaged with during the professional development programme. It would appear therefore that the teachers effectively translated the NoS professional development methodologies into classroom practice. These findings are similar to other studies that revealed that in-service teachers who participated in professional development programme developed effective teaching strategies that positively influenced the development of pupils' NoS conceptions (Akerson et al. 2000; Akerson and Hanuscin 2007; Smith et al. 2000).

Again, one could argue that the children would have developed more sophisticated conceptions of general aspects of NoS if their teachers had not participated in the programme and if their teachers continued implementing the Irish primary science curriculum as they had done prior to participating in the professional development programme. However, again this is unlikely as when their teachers started the programme although all of them had been teaching the primary science curriculum, none of them had ever heard of NoS and had never taught about NoS and all of them held misconceptions regarding 'general aspects' of NoS (Murphy et al. 2015). Indeed, previous studies (for example Abd-El-Khalick 2012a; Griffiths and Barman 1995; Khishfe and Abd-El-Khalick 2002) found that primary school children do not improve their views of NoS simply by teaching inquiry-orientated science activities. It is highly likely therefore that if the teachers in this study had not participated in the professional development, they would not have introduced any NoS pedagogy in their classes. It is probable therefore that the professional development methodologies that the teachers implemented while teaching these children were effective in developing their NoS conceptions. These findings are similar to those of Akerson and Hanuscin (2007) whom also found that participation in a professional development programme focussed on explicit NoS instruction resulted in improved NoS conceptions for the participants' pupils.

Linking School Science to Science

Throughout the exit interviews, the children revealed developing conceptions regarding ‘general aspects’ of NoS and a greater awareness of different scientific process skills they were using during school science. When discussing NoS and scientific inquiry, the children consistently referred to the activities *about* and *in* science they had done in school to substantiate their reflections. It would appear that these children’s engagement with the professional development methodologies has been instrumental in enabling the children to link school science with science in their everyday world, resulting in the children making greater sense of science in their everyday lives.

Conclusion

As stated earlier in this paper, science education policy documents worldwide highlight the importance of scientific literacy and suggest that if pupils are to be scientifically literate they need to develop an understanding of the processes of science and the kind of knowledge science provides as well as being able to apply this scientific knowledge. Furthermore, the educational policy documents suggest that scientifically literate pupils should also be able to foster reasoned arguments and develop the requisite knowledge and skills to understand and take part in the decision-making process regarding socio-scientific issues (Eurydice Network 2011; OECD 2013). While it is not suggested that the primary children in this study hold very sophisticated conceptions regarding NoS, it would appear from the findings that these primary children were beginning to develop their understanding of some ‘general aspects’ about the processes of science and the kind of knowledge science provides suggesting that they are beginning to develop their scientific literacy. While these young children have not yet developed the requisite knowledge and skills to fully understand and consider socio-scientific issues, they were beginning to use their newfound understanding of NoS and experiences of scientific inquiry in school when reflecting on science in their everyday lives. Their engagement with NoS through scientific inquiry during school science appears to have enabled the children to begin to make sense of science by linking their experiences of school science to science and the work of scientists. This provides further evidence that NoS can be successfully embedded into regular classroom science curricula (Akerson et al. 2013; Khishfe 2012; Khishfe and Lederman 2007).

There is much debate about what exactly children should learn about NoS. This study has shown that introducing primary children to ‘general aspects’ of NoS *and* affording them opportunities to engage with and reflect on NoS through scientific inquiry during school science have been effective in addressing NoS misconceptions and in developing their awareness of scientific process skills they are applying during scientific inquiry. The findings of this study support Kampourakis (2016) in that they have revealed that starting with explicit reflective approaches to the ‘general aspects’ conceptualisation of NoS *and* affording children opportunities to engage with and reflect on scientific inquiry appear to be an effective entry point to developing robust conceptions of NoS amongst young children. Previous studies have also found the

‘general aspects’ conceptualisation of NoS to be accessible to children (Akerson and Hanuscin 2007; Akerson and Volrich 2006). Akerson et al. (2011) also assert that including ‘general aspects’ of NoS from an early grade provides pupils with a foundation for learning about NoS, envisaging that pupils who learn about NoS from an early age will develop better scientific literacy. However, if these children are to develop more sophisticated conceptions of NoS, they will require further engagement with NoS pedagogy throughout their primary and post-primary schooling. As a next step, the children would require additional opportunities to engage with and reflect on activities that further explore ‘general aspects’ of NoS throughout their primary schooling. Then as they progress through post-primary school, they should be afforded opportunities to engage with more in-depth conceptualisations of the ‘nature of sciences’ of the different scientific disciplines.

Similar to other countries worldwide (France, Italy, Slovakia, Romania), the Irish primary curriculum does not explicitly include learning objectives regarding NoS (DES 1999). The primary teachers teaching the children in this study had never heard about NoS nor had they ever taught about NoS prior to participating in the programme (Murphy et al. 2015). We would concur with others (Hipkins et al. 2005; Lederman 2007; Yacoubian and BauJaoude 2010) that if teachers are to teach about NoS as part of science curricula, then NoS must be explicitly included as a learning outcome on curriculum documents and assessment tools.

Finally, much research has been published on the impact participation in NoS-related professional development programmes has had on primary teachers’ conceptions of and practice in teaching NoS. However, as noted earlier, there is a dearth of research that has explored whether primary school children are capable of developing contemporary conceptions of NoS or whether targeted NoS professional development can positively affect primary children’s learning about NoS through scientific inquiry. The findings from this study are revealing in these regards as they indicate that primary children can develop proficient conceptions of NoS and that primary teachers can effectively translate NoS professional development methodologies into practice. It has been argued that if professional development is to be effective, it should bring about changes in teachers’ classroom instruction and on children’s learning (Guskey 2003, 2014; Darling-Hammond et al. 2009; Smith 2014). The findings reported in this paper indicate that the professional development programme appears to have been effective in terms of children’s learning about NoS and experiences of scientific inquiry. Professional providers therefore need to invest in the development of a system of high-quality professional development in the area of NoS through inquiry-based science education. The model in this study seems to have been effective in bringing about changes in primary children’s conceptions of NoS and engagement with scientific inquiry within an Irish setting; however, the key characteristics of the project are broad enough to be adapted globally to the specific local needs of teachers and school community environments. It may be particularly valuable in other countries in which inquiry-based experiences and learning about NoS form core pedagogies and where science curricular implementation has also been the subject of some concern.

Appendix 1. Children's questionnaire

Name of School: _____

I am a girl I am a boy

Age Class: _____

Here are some statements about science. How strongly do you agree or disagree with these statements about science? Mark the circle that is closest to your opinion. Only mark ONE box

		Strongly disagree ☹☹	Disagree ☹	No opinion ☺	Agree ☺	Strongly agree ☺☺
1	Science answers questions about the world	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2	Once a science fact is discovered it doesn't change	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3	Scientists use their imaginations when they do experiments	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4	Different scientists can have different answers to the same questions	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5	Scientists usually work alone	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6	Scientists use their opinions when they are explaining things	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7	Scientists use their feelings and beliefs in their work	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8	Scientists make predictions in their work	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9	It is important for people to know about famous scientists in the past	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10	In school we do science activities that help us understand about science observations and inferences	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

11	In class we do activities that show us how scientists use their creativity in their work	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
12	In class we talk about how science is in our everyday lives					
13	My teacher tells us exactly how we should do an investigation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
14	In class we plan how we are going to carry out science investigations	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
15	In class we carry out science investigations ourselves	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
16	In class my teacher usually does the investigations	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
17	In school we record what happens when we are doing investigations	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
18	In school we work in groups when we are doing science investigations	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
19	We ask questions when we are doing science investigations in class	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
20	We talk about whether we are carrying out a fair test	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
21	During science class we always take notes down from the board that the teacher gives	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
22	We discuss results of our investigations in science class	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
23	We get the chance to ask questions in science class	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
24	We make predictions before we carry out science investigations	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
25	We record the results of our investigations in different ways	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Appendix 2. Interview schedule

Nature of science

1. What is science?
2. What do you think of when you hear the word science?
3. What is a scientist?
4. What kind of things do scientists do in their work?
5. Do you think all scientists work in the same way?
 - a. Do you think scientists do experiments in the same way? Why do you think this?
6. Do you think scientists ever use their creativity or imagination in their work? When?
7. Do you think science knowledge can change? Could you explain why you think this?

School science

8. Do you like doing science in school? Why / why not?
9. What kind of things do you do in school science?
10. What kind of things do you like / dislike about school science?
11. If I visited your class to see a typical science lesson, could you describe what I would see?
 - What would you be doing?
 - What would your teacher be doing?
12. Pretend I am going to teach you for science next year. What kind of things would you like me to do with you? What kind of things would you not like me to do with you?

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