



Received: 06 March 2015
Accepted: 17 July 2015
Published: 09 October 2015

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TEACHER EDUCATION & DEVELOPMENT | RESEARCH ARTICLE

Changing practice: An evaluation of the impact of a nature of science inquiry-based professional development programme on primary teachers

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Abstract: This study investigates how a two-year continuing professional development (CPD) programme, with an emphasis on teaching *about* science through inquiry, impacted the experiences of, approaches to and attitudes towards teaching science of 17 primary teachers in Dublin. Data sources included interview, questionnaire and reflective journal strategies. Data gathering focussed primarily on enabling teachers to reflect on their experiences of teaching about science through inquiry while implementing the Irish primary science curriculum. Teachers were also asked to consider their own changes in teaching science, as change in practice is a key indicator of successful professional intervention. Encouragingly the findings have shown that participation in this CPD programme appears to have been central to empowering these Dublin teachers to break away from rather traditional, didactic, theory-laden views of science teaching and to tackle more child-led, open-ended modes of learning. The data also revealed a number of aspects of the CPD model which the teachers perceived to be beneficial at translating inquiry into their

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PUBLIC INTEREST STATEMENT

Educational authorities in many countries have voiced concerns over the declining interest of children in science education. Research has recommended the wider use of inquiry-based approaches in the teaching of primary science to help overcome this decline.

In 2003, a new primary science curriculum began to be implemented in Ireland. This curriculum promotes an inquiry-based approach to learning science. However, since its implementation various research studies have highlighted concerns regarding the teaching and learning of primary science in Ireland, including infrequent employment of inquiry-based methodologies and lack of confidence amongst primary teachers in teaching science.

This article explores the relationship between teacher involvement in an inquiry-based, sustained, collaborative professional development programme and how this programme impacted their confidence and change in classroom practice. Findings reveal that as a result of their involvement in the programme teachers' confidence in teaching science increased and their instructional practice in science lessons became more inquiry based.

classrooms, in particular: the active, hands-on approaches; the collaboration and the duration of the CPD itself. Based on the findings of this study, implications for professional development are considered.

Subjects: Adult Education and Lifelong Learning; Primary Education -Teaching Practice; Teacher Education & Training

Keywords: primary science; inquiry-based science education; nature of science; continuing professional development

1. Introduction

Research indicates that children's interest in science declines as they move through primary school (Murphy & Beggs, 2003; Murphy, Beggs, Carlisle, & Greenwood, 2004; Murphy, Neil, & Beggs, 2007; Pell & Jarvis, 2001). A number of factors have been put forward to explain this decline, including: inappropriate curriculum content, preparation for national tests, type of teaching and lack of experimental work. However, according to Murphy et al. (2004), the decline is less apparent when children are involved in practical, investigative activities. Over the past two decades there has been a world-wide move towards utilising inquiry-based science education (IBSE) curricula and teaching methodologies in primary school classrooms (Akerson & Hanuscin, 2005; Cuevas, Lee, Hart, & Deaktor, 2005; Murphy, Murphy, & Kilfeather, 2011). In Europe, the European Commission published a report (Rocard et al., 2007) on concerns about the declining interest of young people in science education. One of the main recommendations of the report was the wider use of inquiry-based approaches in the teaching of primary science to help increase the engagement and interest of pupils in science.

In Ireland a significantly revised primary science curriculum (PSC) was introduced in 1999, although formal implementation did not commence until 2003. While the revised PSC (Department of Education and Science [DES], 1999a) does not explicitly refer to IBSE methodologies, it emphasises an IBSE approach embedded in a social constructivist epistemology. In addition to the emphasis placed on the development of pupils' scientific conceptual understanding and skill development, the PSC also aims at supporting pupils in developing a scientific approach to problem-solving, emphasising understanding and constructive thinking.

Prior to implementation of the PSC in 2003, all primary teachers participated in nationally organised professional development. This consisted of two days' in-service workshops in an identical format provided to all schools, with one additional day for school planning. The sessions focussed on providing an overview of the PSC with opportunities for teachers to engage in limited exemplar "hands-on" activities. Since the initial two days in-service prior to implementation in 2003, no further national Continuing Professional Development (CPD) programme has been made available to support primary teachers in teaching science.

Since the roll out of the PSC in 2003 various research studies have been published that highlight concerns regarding the teaching and learning of primary science in Ireland. These include: infrequent employment of hands-on investigative and inquiry-based methodologies; lack of confidence amongst teachers in teaching science; poor scientific content and pedagogical knowledge amongst primary teachers and insufficient provision of long-term professional development programmes for teachers (Department of Education and Skills, 2012; Murphy & Smith, 2012; Murphy et al., 2011; National Council for Curriculum and Assessment [NCCA], 2008; Smith, 2013). One of the key aspects for improving the teaching of primary science that has repeatedly been identified in international research is the need for effective CPD for primary teachers (Murphy & Beggs, 2005).

This article considers some of the salient features of a recent CPD programme in primary science that took place in Ireland and examines the impact that participation in this CPD programme had on teachers' confidence in, attitudes towards and practices in teaching science. The conceptual

framework for the current study is based on Desimone's (2009) core conceptual framework (p. 184) for studying the effects of professional development on teachers and pupils.

- Teachers' participation in effective professional development
- Changes in teachers' scientific pedagogical knowledge and attitudes towards IBSE and primary science
- Changes in teachers' classroom practice
- The instructional changes promote increased pupil learning.

This paper reports on data relating to the first three steps of Desimone's framework. In particular this article addresses the following two research questions:

- (1) To what extent did the CPD programme impact on teachers' experiences of, approaches to and attitudes regarding teaching science?
- (2) What were the teachers' perceptions of the most effective components of the CPD programme?

2. Review of the literature

The PSC in Ireland, in common with developments in many such curricula internationally, seeks to promote an inquiry-based approach to learning science (DES, 1999a). IBSE has been advocated as an essential focus for school science, with its potential to enthuse and motivate pupils and to permit the development of crucial intellectual skills in addition to facilitating the acquisition of scientific knowledge (Artique et al., 2012; Harlen, 2010; Krogh & Thomsen, 2005; Murphy, Kilfeather, & Murphy, 2007; Murphy et al., 2011; Rocard et al., 2007). Scientific inquiry in this sense goes beyond the following of practical protocols to verify established outcomes, despite this approach being common in some school science curricula (e.g. DES, 2004). Supporting teachers' skills in facilitating this aspect of science would therefore appear to be a key to improving curricular implementation.

Broadly speaking the term, inquiry refers to an *act of building and testing knowledge*. A process that requires the active role of the pupil, the learning of science starting with *questions* rather than answers, and drawing on what is already known, but going beyond it (Artique et al., 2012, p. 4). Harlen (2010) asserts that there is more to inquiry than "hands-on experience" and outlines other key aspects of the inquiry process, including making observations, asking questions, planning and carrying out investigations, interpreting and reporting data. Harlen (2010) also maintains 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. (p. 3)

Abd-El-Khalick et al. (2004) outline differences between inquiry *in* science and inquiry *about* science. They define inquiry *in* science as "an instructional approach intended to help pupils develop understandings of science content" and inquiry *about* science as "inquiry as an instructional outcome" (p. 398). They assert that pupils learn to do inquiry in the context of science content and develop epistemological understandings *about* science and the development of scientific knowledge as well as relevant inquiry skills. The term nature-of-science (NoS) is frequently used in reference to issues *about* science and relates to matters regarding what science is, how it works, how scientists work as a social group and how science influences and is influenced by society.

The research literature has highlighted numerous benefits of learning *about* science. Some contend that when pupils learn *about* the nature of science (Nos) in science class, they become more aware of the developmental NoS and science as a human activity, making it more interesting for them to learn (Abd-El-Khalick, 2012; Khishfe & Lederman, 2007; Mc Comas, Clough, & Almazora, 1998). Others

contend that pupils who leave school with contemporary understandings *about* science have a better understanding of science concepts and scientific inquiry, a greater interest in science and have a better appreciation of science's role in contemporary society (Craven, Hand, & Prain, 2002; Driver, Leach, Millar, & Scott, 1996; Lederman, Antink, & Bartos, 2014; Murphy, Kilfeather, et al., 2007).

If it is accepted that teaching *about* science is an important aspect of school science then it would be essential for teachers to have well-developed pedagogical knowledge *about* science. Research indicates, however, that this is not generally the case for many primary teachers (Lederman, Abd-El Khalick, Bell, & Schwartz, 2002; Pomeroy, 1993). The authors contend that if teachers were provided with professional development that focuses on learning *about* science and learning *in* science pedagogy, teachers would become more confident about using more child-led, inquiry-based approaches. Previous work with pre-service primary teachers in an Irish context had already indicated that this approach could be beneficial in this regard (Murphy & Smith, 2012; Murphy et al., 2011).

However, aside from decisions of content, another imperative to consider is the way in which the CPD should be structured so as to support teachers most effectively and hence promote substantive changes in classroom practice.

3. Professional development

Professional development is defined as a process that leads to improvements in teachers' knowledge, classroom practice and pupils' learning outcomes (Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009; Desimone, 2009; Loucks-Horsley, Stiles, Mundry, Love, & Hewson, 2009). There is considerable criticism in the literature of "traditional" forms of CPD (e.g. Desimone, 2009; Hawley & Valli, 1999; Hoban, 2002; Loucks-Horsley et al., 2009). Hawley and Valli (1999) claim that, "Conventional approaches to professional development, such as one-time workshops, typically do not lead to significant change in teaching methodologies" (p. 129). Hoban (2002) argues further, that such approaches do not consider: the context of the school, attitudes of teachers to change, and that teacher change is more a process than an event.

The last two decades have seen the growth of an extensive body of research illustrating the various features of "effective" professional development needed to improve teaching and pupil outcomes (summarised by e.g. Darling-Hammond et al., 2009; Desimone, 2009; Guskey, 2002). Guskey (2002) argues that the primary goal of professional development is to generate transformation in teachers' classroom practice, in teachers' attitudes and beliefs, and in the learning outcomes of pupils. Even though educationalists have suggested diverse features of effective professional development, common features have been identified from an abundance of research into professional development. (e.g. Darling-Hammond et al., 2009; Desimone, 2009; Guskey, 2003; Loucks-Horsley et al., 2009). These include: focus on content, active learning, coherence, duration and collective participation (Desimone, 2009). These features imply that professional development is more than a series of one-off workshops; it is a way of putting knowledge into practice within a community of actively engaged practitioners. Guskey (2002) recommends three guiding principles necessary in the planning of effective professional development programmes: (a) acknowledge that change is an ongoing and complicated process, (b) ensure that teachers obtain frequent feedback on pupil learning progress and (c) provide continued follow-up, support.

Traditionally, programmes of professional development, as understood in the Irish context, tend to be provider-driven "one-off" courses, or short modular courses provided by the DES. Recent reports (Organisation for Economic Cooperation & Development, 2009; Teaching Council of Ireland, 2009) identified concerns relating to CPD in Ireland. Namely, that provision is still generally short-term and mainly relates to implementation of national curriculum programmes, with little prominence given to the professional development needs of individual teachers. There is considerable criticism in the literature of such forms of CPD (e.g. Desimone, 2009; Hawley & Valli, 1999; Hoban, 2002; Loucks-Horsley et al., 2009). Hawley and Valli (1999) claim that, "Conventional approaches to

professional development, such as one-time workshops, typically do not lead to significant change in teaching methodologies” (p. 129).

4. Design and methods

4.1. The CPD programme

The main aims of this two-year CPD programme were to bring about progressive changes in teachers’ confidence in and approaches to teaching *about* science through inquiry while implementing the PSC. The study was conducted in 10 primary schools in the Dublin urban area. Involvement of the schools was based on a commitment on the part of each school principal that at least two teachers from the school would be enabled to participate in the CPD programme for the full two years. The participating teachers taught classes in the upper primary age range (age 8–12 years).

4.1.1. Content

Throughout the workshops social constructivist approaches to teaching and learning science as advocated by the PSC (DES, 1999a) were modelled and encouraged. The workshops provided teachers with opportunities to engage with and reflect on a range of different teaching methodologies and resources that were grounded within a social constructivist framework. These included: the use of concept cartoons and concept mapping as means of formative and summative assessment; ways to plan, conduct, record and report fair test and open-ended investigations; and the use of digital technology in planning investigations, recording, interpreting and analysing results, and in reporting and presenting findings. A range of different teaching methodologies suitable for teaching science, as outlined in the PSC were modelled throughout the workshops. These included: closed activities; teacher-directed and child-led open investigations; activities designed to provide pupils with opportunities to develop particular science skills; and using digital technologies in science class.

There were two underlying themes that ran through every workshop. Namely pedagogy regarding the use of: inquiries *about* science and; inquiries *in* science. Inquiries *about* science are tasks that do not focus specifically on scientific content, but focus on a particular aspect *about* the NoS (e.g. how scientists work, the tentative NoS, subjectivity and objectivity in science). Inquiries *about* science introduce a concept about science to the children using a non-science context. The children do not have to try to grapple with scientific content; they just focus on the particular aspect *about* science that is being addressed. These aspects are initially introduced to the children using a non-science context as it makes it easier for the children to reflect on and to consider these issues when they are carrying out scientific investigations. Aspects *about* science that were addressed on the CPD programme included science as a body of knowledge, the nature of scientific inquiry, science as a human activity, how science and society are affected by one another, and the importance of the history of science in science education. The *Tricky Tracks*, the *Tube and the Cube* activities (Abd-El-Khalick & Lederman, 1998) are examples of the type of inquiries *about* science with which the teachers engaged during the programme.

Inquiries *in* science, on the other hand, are activities that have a scientific context but also focus on different aspects *about* science. The content in the inquiries *in* science in the CPD programme was drawn from the *Living Things*, *Energy and Forces*, *Materials and Environmental Awareness and Care* strands in the PSC (DES, 1999a). These inquiries provided the children with opportunities to plan and carry out a range of investigations in order to answer different scientific questions. As well as developing children’s scientific content understanding and skill development, these activities also aimed at affording pupils with frequent opportunities to reflect on and discuss issues relating to the NoS.

4.1.2. Workshops and implementing approaches in the classroom

Over the course of the programme there were 18 three hour long workshops. These assumed a hands-on participatory approach whereby the teachers, working in small groups, had the opportunity to engage with the various activities and investigations prior to teaching them in their classrooms. There were ample opportunities in every workshop for the teachers to discuss and reflect on

the different activities. In between each workshop the teachers were required to try out the different activities and methodologies, with which they had engaged during the workshops, in their classes. A major feature of each workshop was the building up of trust between the participants as a group, and with the researchers. Teachers were encouraged to share and reflect on their experiences (both successes and challenges) of implementing the different approaches and activities in their classes. Traditionally, with quantitative research the researcher undertakes “detached” role. However, qualitative research cannot be as objective. The researchers had a key role to play in this study trying to provide merited ideas for enhancing the capacities and attainments of the teachers involved. Based on the researchers’ knowledge of professional development, science education and experiences carrying out research, they believed that they were qualified to carry out this research and bring a unique perspective to the interpretations. The intervention programme used in this research was designed by the researchers. Thus, the researchers’ beliefs and values regarding the teaching of science and what constitutes effective professional development (informed by the research literature) were embedded in the research. However, every effort was made to ensure objectivity when analysing the data.

Over the course of the programme the researchers provided ongoing support for all the participants. This took the form of visiting all the participants in their schools, a virtual learning environment (Moodle), and e-mails. The researchers assumed various roles during these visits including teacher, co-teacher, observer and working with groups of children.

4.2. Participants

Twenty-two teachers signed up to the programme. However, at the beginning of the second-year five of the teachers had to drop out of the programme for personal and professional reasons. Three new teachers joined the programme for the second year. Only 17 of the teachers participated in the project for the entire two years. This paper reports on the findings from data gathered from these 17 teachers.

Table 1. Personal characteristics of participating teachers (n = 17)

	Frequency	Percentage
Gender		
Male	03	18
Female	14	82
Teaching experience		
0–5 years	02	12
6–10 years	09	45
11–15 years	01	06
16–20 years	02	12
Over 20 years	03	18
Highest qualification in science		
Junior/inter certificate state exam (age 16)	04	24
Leaving certificate state exam (age 18)	10	60
Degree	01	06
None	02	12
Science professional development courses attended		
Post graduate diploma in science education	01	06
Curriculum implementation in-service days	08	48
Summer course in teaching college	04	24
Other	04	24
None	05	30

These 17 teachers represented a range of backgrounds in terms of: years of experience in teaching; prior science qualifications; and previous attendance at science education-related professional development courses (Table 1).

4.3. Data collection

Over the past twenty years or so, researchers (e.g. Creswell 2003; Johnson & Onwuegbuzie, 2004) have advocated using features of both quantitative and qualitative methods in the same study i.e. a “Mixed Methods approach” to research. Patton (2002) stresses that researchers: “need to know and use a variety of methods to be responsive to the nuances of particular empirical questions and the idiosyncrasies of specific stakeholder needs” (p. 585). Owing to the nature of the research questions, a mixed-methods approach was deemed the most appropriate approach to this study. According to Johnson and Onwuegbuzie (2004) a mixed-methods approach, “allows researchers to mix and match design components that offer the best chance of answering their specific research questions” (p. 15). To this end, data were gathered via questionnaires, interviews and reflective journals. Teachers were asked to consider their own change in classroom practice of teaching science, as change in practice is a key indicator of successful professional intervention (Darling-Hammond et al., 2009; Guskey, 2002). The teachers were also asked to reflect on components of the CPD programme that they believed were effective in supporting their professional development.

4.3.1. Teacher questionnaire

The format for the questionnaire used in this study was adapted from a questionnaire used with pre-service teachers in an earlier study looking at the impact of a pre-service course on teaching about the NoS (Murphy & Smith, 2012). There were three sections in the questionnaire. The first section (A) gathered information regarding professional qualifications and context. Section B asked teachers to rate their confidence about teaching all areas of the curriculum, in a bid to establish how confident they felt teaching science in comparison to the other areas of the curriculum. Finally, Section C sought to gain information about the teachers’ views about science, their attitudes towards and practices in teaching science, and their conceptions of NoS. This section contained three open-ended questions and 39 statements about NoS and classroom practice to which the respondents had to indicate the extent to which they agreed/disagreed with each statement. It is important to note that for the purpose of this paper only the data gathered from the teachers’ responses to questions in Section A and the open-ended questions in Section C are reported.

Piloting of the questionnaire was carried out with four non-participating, qualified teachers to ensure acceptable content validity. Participants were asked to complete the questionnaire at the beginning of the first CPD workshop of the programme, and at the end of last CPD session. Entry and exit questionnaires were matched for each of the participants so that their responses could be triangulated with other data gathered. This prevented the responses from being anonymous; however, confidentiality was assured for this process. To determine content validity a panel of three educators reviewed all of the items in the questionnaire for readability, clarity, comprehensiveness and to ensure they addressed the objectives and purposes of the programme.

4.3.2. Interviews

A semi-structured interview schedule was designed and aimed at establishing teachers’ experiences within the two-year CPD programme and their perceptions of how their pedagogical knowledge of science had developed. After piloting with two non-participating teachers, interviews were conducted by the researchers at the end of the two-year CPD programme. Interviews were taped and transcribed for analysis.

4.3.3. Reflective journals

At the beginning of the CPD programme the teachers were given a reflective log. They were asked to complete the reflective log after each workshop and after teaching the different activities back in their classrooms. A general list of questions was compiled and agreed on by the researchers and teachers. However, it was made clear that this list of questions was only a guideline and that the

teachers did not have to adhere rigidly to the list when reflecting on the workshops and science lessons they had taught. The purpose of the reflective journals was to gain an insight into the teachers' ideas and experiences of learning about and implementing the new methodologies over the two years of the programme.

4.4. Data analysis

Glaser and Strauss (1967) "constant comparative" method of data analysis was utilised. When the data from the questionnaires, interviews and reflective journals were analysed, a set of categories that provided a "reasonable" reconstruction of the data collected was developed. Category names were ascribed to the units of meaning and the data were then grouped into categories with related content. As recommended by Lincoln and Guba (1985), rules for inclusion were devised as "propositional statements". These propositional statements communicated the meaning that was embodied in the data collected under each sub-category. The responses from all three data sources were initially explored under three categories that related to the research questions. A number of sub-categories then emerged in all three categories, as outlined in Table 2. Three raters rated the questionnaire, interview and reflective journal data and an inter-rater reliability of 97, 96 and 96%, respectively, was established.

5. Findings

The findings are presented according to the categories and sub-categories (Table 2) that emerged from the analysis of the questionnaire, interview and reflective journal data.

5.1. Teachers' perceptions of the impact of the CPD programme on their professional development and classroom practice

5.1.1. Pedagogical knowledge

Prior to the CPD intervention, the teachers were asked what they hoped they would gain from participating in the CPD programme. In the initial questionnaire all 17 of the teachers indicated that they hoped to develop their pedagogical understanding of and confidence in teaching science. The desire to learn about methodologies that would engage pupils, would involve active, discovery-based learning, and that would facilitate collaborative learning were also referred to in response to this question. Typical responses included, "to get a better understanding of how to teach science and new methods of how to teach" and "I hope to become a better teacher of science".

Table 2. Categories that emerged from analysis of questionnaire, interview and reflective journal data

Category	Sub-categories
Teachers' perceptions of the impact of the CPD programme on their professional development.	<ul style="list-style-type: none"> • Pedagogical knowledge • Confidence • Attitudes
Teachers' perceptions of the impact of the CPD programme on classroom practice	<ul style="list-style-type: none"> • Teacher directed Vs Child- led • Development of science skills • Language and dialogue • Reflecting/thinking skills • Pupil collaboration • Problem solving • Children's attitudes towards science
Teachers' perceptions of the CPD model	<ul style="list-style-type: none"> • Duration • Collaboration • Reflective practice • Hands-on

In the exit questionnaire and interviews the teachers were asked “what they had gained from participating in the CPD programme?” All of them maintained that they had learned a range of new methodologies for teaching science. The teachers indicated that these were not approaches with which they had engaged or content that they had addressed in their teaching prior to their participation in the programme.

Lots of new ideas on what and how to teach science, especially Nature of Science ... and ways to help children develop their scientific skills, like questioning, observing and inferring etc. (Exit questionnaire)

In the interviews 14 of the teachers also reported that they now teach science more frequently than they had prior to their involvement in the programme.

5.1.2. Confidence

Somewhat surprisingly, only five of the teachers asserted in the initial questionnaire that they hoped to gain confidence in teaching science. However, in the exit questionnaire and interviews all of the teachers stated that they felt more confident about teaching science as a consequence of their participation in the CPD programme. A range of reasons were provided. Perhaps predictably, the teachers emphasised that having the opportunity to carry out activities for themselves in the CPD sessions was a means of gaining confidence to undertake them in the classroom:

I didn't feel in any way confident teaching science before ... But now, since doing the science workshops I feel way more confident teaching science ... and the fact that we experienced the activities ourselves during the workshops really helped me. (Interview)

However, significantly in relation to the teaching *about* science focus of the CPD programme, a key issue cited by teachers in developing their confidence in the classroom was their altered perspective on scientific subject knowledge. In the initial questionnaires, a problem stated by many of the teachers was that they did not have the requisite scientific knowledge to deal with questions from children. This fear of not being able to answer pupils' questions was a cause of concern for the teachers. However, in the reflective journals and interviews the teachers asserted that they had come to realise that it was not absolutely necessary to know all the answers in order to teach science to their pupils.

I feel more confident teaching science now because it's not something where I feel I have to be the expert who knows the answers to everything ... (Interview)

The researchers do not wish to imply from this that enhancing teachers' subject knowledge is irrelevant to generating confidence in primary science teaching. On the contrary, it is contended that helping teachers to understand about the tentative, developmental nature of scientific knowledge empowered them to embark on a journey of inquiry and fact-finding together with their pupils, rather than scientific knowledge presenting a formidable barrier that had to be overcome in advance of any teaching. However, factors other than science knowledge can affect teacher effectiveness in primary science. These include teachers': interactions with children in lessons; capacity to select appropriate experiences for pupils; and attitudes towards the subject. According to Golby, Martin, and Porter (1995) if teachers appreciate in a broad sense the NoS then they can involve pupils in enjoyable science activities. Furthermore, they state “teaching is not principally about telling facts but about finding meaning in experience” (p. 299). Effective professional development programmes should afford participants time to discuss and develop their ideas as well as enhancing their subject knowledge.

5.1.3. Teacher directed V child-led investigations

In the exit questionnaires and interviews all 17 teachers indicated that, prior to the programme, when they had been conducting hands-on activities in science class these had tended to be teacher-directed. Typically they would conduct an experiment and let the children watch or they would give

prescribed steps for the children to follow. In the exit questionnaires and interviews the teachers asserted that they had moved towards more child-led approaches, where inquiry was now the focus when teaching science. Significantly, all of the teachers were explicitly reflective of the fact that they were now adopting roles as facilitators of the children's learning in science and moving away from more didactic approaches.

It has made me more confident in teaching science in school. It has allowed me to be less rigid in following recipe style investigations. The children enjoy science much more by being more involved in designing their own investigations and doing the science activities themselves. (Exit questionnaire)

Teachers' responses in the reflective journals revealed that at the beginning of the CPD programme they felt "out of their comfort zones" when they initially began to implement the new methodologies, as these were not approaches to science that they had typically used prior to the CPD programme. Journal entries and interview data alike indicated that prior to the CPD these teachers placed a strong emphasis on their pupils following *scientific steps* and *learning scientific facts* and that they tended not to afford their pupils opportunities to develop their understanding *about* science or to carry out their own inquiries:

The children came up with the ideas of what was the best bubble. They then decided on what THEY¹ wanted to test, how THEY would test it, how THEY would make a fair test, how THEY would record their results, how THEY would present their results ... The different groups came up with a variety of different ways to carry out their investigations and to present their results. I used this opportunity to highlight how there is no one scientific method that every scientist rigidly adheres to ... (Reflective Journal, Year 1, Month 10)

It was also apparent from the teachers' responses in both the reflective journals and the interviews that, as a result of the CPD programme and their newfound knowledge of teaching *about* science, this situation appears to have reversed, with less insistence, for example, on pupils *getting the right answer* and more emphasis on pupils *coming up with their own methods for answering a scientific question*. One teacher commented that:

... [Before the CPD] I would really just have thought of science as a body of knowledge that you kind of had to impart to the kids ... Whereas now, you look more at aspects of Nature of Science, like for example science as a creative process and how scientists get knowledge (Interview)

As stated in the literature review section, one important component of effective CPD is that teachers utilise ideas from the CPD in their classes (Desimone, 2009; Guskey, 2002). It would appear from the interview, questionnaire and reflective journal data, that these teachers had tried out the new methodologies for teaching science that they had learned about during the workshops. These findings are perhaps not surprising as one of the requirements of the programme was that the teachers had to implement the workshop methodologies in their classrooms. What is interesting about the data obtained was the teachers' perceptions of the positive impact learning *about* science through inquiry had on their pupils' experiences of school science.

5.1.4. Development of pupils' science skills

The teachers offered a range of reasons as to why they believed teaching *about* science was an important component of primary science. Data from the reflective journals and interviews in particular indicated that all of the teachers felt strongly that learning *about* science through inquiry had a considerable positive impact on the application and development of pupils' scientific skills. In their journals the teachers frequently reflected on the range of scientific skills their pupils had been applying while engaging with the inquiries *about* science. These included: questioning; making observations and inferences; predicting; planning and carrying out independent investigations; recording,

analysing and interpreting results—which accord well with the key skills explicitly mentioned in the Irish PSC (DES, 1999a).

The data from the reflective journals were analysed prior to the interviews being conducted. As the teachers had reflected in their journals on how the inquiries *about* science activities helped develop pupils' scientific skills, this was raised in the interviews. All 17 teachers reiterated that they believed that engagement with the inquiries *about* science did support the development of a range of science skills. Typical responses included:

... You can see them ... without being prompted now, making observations and inferences, making predictions. They can carry out or plan their own investigations a lot more easily than they would have before ... And even, say, discussion and recording results ... they do a lot more of the skills automatically (Interview)

5.1.5. *Pupil collaboration*

The reflective journal data also revealed that all the teachers thought that engagement with the inquiries *about* science activities provided frequent opportunities for their pupils to work collaboratively. A typical quote:

The group discussions were wonderful. The children were in small groups and therefore the quieter children seemed to contribute more. Some groups got quite animated at times trying to show each other examples of how things move or how they work (Reflective Journal, Year 1, Month 3)

When asked how engagement with the inquiries about science activities impacted on children's experiences of school science. The majority (14) of the teachers stated that they believed that learning about science through inquiry provided more opportunities for collaboration in science class, a significant skill in relation to scientific working. The teachers reflected both on teachers and pupils collaborating together to find solutions and pupils collaborating with one another.

... It's more that we work together as a group ... It's the children as well having a huge involvement in everything ... and I'm finding now that in my own classroom, that science is a time where we all become involved and we're all hands-on and we're all asking questions (Interview)

5.1.6. *Language development*

All of the teachers also reported that while engaging with the inquiries *about* science, pupils were collaborating and developing language skills while planning, conducting, recording and reporting back on their investigations. An emphasis was placed on the use of oral language skills when pupils were describing investigations, interpreting results and discussing evidence they had gathered to support their theories. Additional opportunities for oral language development were provided when pupils had to discuss and justify decisions they had made during their different inquiries.

5.2. ***What were the teachers' perceptions of the most effective component of the CPD programme?***

In the questionnaires and interviews the teachers were asked a range of questions regarding their perceptions of effective professional development. The teachers identified several characteristics of the professional development model that they believed lead to changes in their teaching practice. The four most frequently discussed characteristics of effective professional development outlined by the teachers were: active participation; collaboration; reflective practice and the duration of the professional development programme.

5.2.1. *Active hands-on approach*

A key factor for effective professional development that the teachers cited in the exit questionnaire and interviews was active participation. The teachers reported that the CPD programme provided them with frequent opportunities to engage with a range of hands-on, reflective, inquiry-based

activities that were relevant to their classroom practice and helped them develop a better understanding of science pedagogy.

This CPD programme was a lot easier [than other forms of CPD] because you were involved in it. It's the same for children ... it just sticks in your head when it's hands-on (Interview)

I really enjoyed the workshops ... they were so hands-on and practical and easy to understand. It was very easy to take the work we did in the workshops into the classroom (Exit questionnaire)

Another reported benefit of engaging with the activities during the CPD workshops was that teachers were faced with similar situations and dilemmas as those that their pupils would face. Engaging with and reflecting on the activities in the workshops gave teachers an insight into some of the problems their pupils might encounter when engaging with the science activities in the classroom. The following comment supports this claim:

We were practising how we should be teaching science ... we were put into the position of the children and I experienced some of the problems and obstacles they can face when learning science ... It was interesting to see how different groups [teachers] came up with different ideas to do the investigations. This also gave me an idea of the different ideas my pupils might come up with when they would be doing the investigations themselves (Interview)

Data from the reflective journals corroborated the findings from the questionnaires and interviews. The following reflective journal extract is representative of the teachers' comments on the need for professional development to be active in nature.

Having actually done the investigation myself in the workshop I saw how straightforward it was and how enjoyable it was and it gave me the confidence to actually do the experiment in class. (Reflective Journal, Year 1 Month 9)

Overall, the teachers maintained that for a professional development programme to be effective it needs to actively engage them as learners.

5.2.2. Collaboration

All 17 teachers asserted that a particularly positive aspect of this CPD model was the strong emphasis placed on collaboration. There was a general consensus that unlike other forms of professional development that they had attended, this model provided frequent opportunities for them to work with other teachers on the programme.

I have learned a huge amount from talking to other teachers and getting their perspectives ... we worked collaboratively on a path towards deeper understanding of the Nature of Science (Interview)

The teachers also indicated that the on-going sharing of ideas and meaningful discussions with other teachers on the programme helped inform their approaches to teaching science more broadly.

... meeting other people [teachers] as well and seeing how things do or don't work and, you know, getting new ideas [from other participants] and, if it [a particular activity] didn't work for me, seeing what the other teachers did that was different, and [to hear about] what worked for them (Interview)

Evidence from the data suggested that all the teachers developed "critical friendships" (Costa & Kallick, 1993) around the teaching and learning of science, with the other participating teacher(s) in their school. All the teachers indicated that these critical friendships were a particularly positive aspect of their engagement with the CPD programme and enabled them to work together in planning lessons, developing resources, teaching lessons and reflecting on the teaching and learning of NoS.

I think having two teachers in the same school [on the programme] was really useful because we both worked well together and we bounced ideas off each other all the time. Sometimes I'd go into her class for her lesson if it was a new lesson or she'd come into mine and help on a day to day basis (Interview)

Twelve of the teachers also collaborated closely with teachers in their schools who had not taken part in the CPD and eight organised whole school CPD sessions to extend the benefits of their experience to their colleagues.

During our staff meeting our principal gave us time to talk about the methods of teaching science we had learned about during the programme. We also did a few short workshops with our staff. These workshops gave them the chance to try out some of the activities we had done so they could try them out with their classes (Interview)

We are doing a series of workshops with staff so they can benefit from what we learned (Interview)

This led to meaningful collaboration in a number of schools where teachers who did not participate in the CPD programme even sat in teachers' (who had taken the CPD programme) classrooms to observe them teaching science.

Myself and [the other participating teacher] colleague presented to the whole staff ... 60-70% of teachers have come back looking for ideas and lessons. I have people [teachers] come in to my class, watch me teach science ... they will go off and try it themselves (Reflective Journal, Year 2 Month 8)

The design of this CPD model had intentionally recruited more than one participant from each school, in order to foster a collaborative approach from the outset. It was hoped that this would facilitate further sharing of ideas back in those teachers' schools to the non-participant colleagues, and the evidence suggested that this had happened. A broader outcome of the project, however, was the development of a professional learning community (Hord, 2009) between participants from different schools. Over the course of the programme the teachers began to exchange ideas and resources with participating teachers from other schools, exchanges which all teachers found particularly beneficial.

I learned a huge amount from talking to other people and getting their perspectives. For example, Teacher 2 [teacher from a different school] on the course ... I have learned so much from conversations with her regarding the ways that she was addressing the activities [from workshops] with a similar age group to me, I was able to come back [to school] and say "okay" I'm going to try some of those ideas (Interview)

Overall, it would appear that the collaborative approach that was fostered between participants on the CPD programme, during workshops, had developed further and translated into developing those collaborative approaches and relationships in other professional settings.

5.2.3. *Reflective practice*

A very important feature of the workshops was to provide teachers with opportunities to critically reflect on their roles as teachers and as learners, with a view to bringing about change in their classroom practice. Reflective practice included discussions about: the research-based methods modelled in the workshops; teachers' experiences as pupils in the workshops; successes and challenges of using activities back in the classroom.

Confirmation of the development of self-reflection and group reflection is apparent from the following comment that was typical of those made by teachers during interviews and exit questionnaires.

I found it really useful to talk to teachers in other schools who are teaching the same age group. You can share ideas and resources. It is something I rarely get a chance to do and I think it is very important for a teacher. It helps you think about what you are teaching and see if there are other ways you can go about teaching (Interview)

However, it is important to note that it was not until the latter part of the project (start of Year Two) that the teachers fruitfully began to develop their capacity for self and group reflection. This is very understandable as many of the teachers were not accustomed to sitting around a table discussing their teaching practice. Time was required to build up trust. The on-going nature of the CPD programme gave the participating teachers' time to reflect on their teaching and instigate changes in their classroom practice.

5.2.4. Duration

Data from the interviews revealed a strong consensus amongst all the teachers that the traditional type of in-service courses that they had experienced prior to this CPD programme tended to be too short in duration and yet overloaded with content. They also claimed that the brevity of the other types of courses did not allow them the opportunity to return to their classrooms and try out what they had learnt and to discuss their practice at a follow-up workshop. Furthermore, in the previous in-service workshops the teachers had attended no additional support was available to them once the workshop was completed. Therefore, they tended to abandon new approaches at a very early juncture. This finding supports Guskey's contention that "If the use of new practices is to be sustained and changes are to endure, the individuals [teachers] involved need to receive regular feedback on the effects of their efforts". (2002, p. 387).

With the one off, one weekend professional development, you get lots of ideas. You might take two or three ideas from that ... if they don't go right [in the classroom] you forget about it and don't do them again (Interview)

Insufficient time to get to know other teachers was another reported negative aspect of the short in-service courses, with which the teachers typically engaged prior to this CPD programme.

Other courses [CPD] are over such short time periods you don't get to know anyone, here you build up a relationship. In this programme I got to know the teachers from other schools very well. We had good discussions in the workshops, particularly when we were working in groups, but also in the whole class discussions that we had every workshop (Interview)

Discussing the current CPD model had caused the teachers to reflect on the inadequacies of earlier types of CPD experienced and, indirectly, to pinpoint the features of the current CPD model that had been beneficial. Significantly, all participants spoke favourably and more directly of the duration of the model, which they indicated introduced new developments in a gradual way and provided a long-term sustainable form of CPD. The teachers outlined a number of benefits of the longer duration of this CPD model with which they had engaged.

All the teachers stated that one of the most significant benefits of this longer term approach to CPD was that it provided them with considerably more frequent opportunities to try out the new ideas in their classrooms and regular opportunities to share their experiences with the other participants.

Spreading it [CPD] out over that length [two years] definitely enhanced the professional development ... you get a chance to test them [workshop activities] out ... come back, discuss them [activities in classroom] and share with other people (Interview)

In the exit questionnaires, the teachers also reflected on what they perceived to be the benefits of a longer duration CPD programme. Typical comments included,

... because it [the CPD programme] was on-going you knew well if it [innovative approach] did not work out for you back in the classroom you could talk about it at the next workshop, or contact one of the lecturers (Exit questionnaire)

The teachers maintained that this more gradual approach to CPD was more effective and that they learned a considerable amount from each other's experiences:

With this [CPD programme] because it was a two-year programme, we were slowly building up various different things and it was learning from each other, we could see the progression ... it was an evolving process (Interview)

6. Discussion and conclusion

The findings from this study demonstrate the potential of a targeted participatory professional development programme to bring about positive changes in teachers' confidence in and approaches to teaching science.

Prior to engaging with this CPD programme the teachers asserted that they hoped they would develop their pedagogical understanding of and confidence in teaching science. The evidence suggests that these aspirations were met. It would appear from the data gathered that the opportunities afforded to the teachers, for engaging with and reflecting on inquiry-based approaches to teaching science in the classroom, has resulted in change in their experiences of, approaches to and attitudes regarding teaching science.

In particular, the main focus of these teachers' science lessons seems to have moved away from teacher-led expositions of scientific content towards a greater emphasis on the application and development of pupils' scientific skills. Inquiries *about* science as a "lens" through which to view science and hence science teaching appears to have been central to empowering the teachers in the current study to break away from rather traditional, didactic, theory-laden views of science teaching and to tackle more child-led, open-ended modes of learning. Teachers in particular appear to have been embracing views of the tentative, developmental and human-centred NoS as core aspects of their new teaching approaches.

The teachers' reflections on teaching *about* science throughout the CPD programme indicate their belief that teaching *about* science as part of the PSC provided their pupils with more frequent opportunities to discuss their ideas, to plan and carry out their own investigations, to apply a range of scientific skills and to work collaboratively. Thus, including inquiries *about* science as part of the PSC appears to have provided a possible means by which to enact an improved implementation of the PSC (DES, 1999a), with its greater emphasis on inquiry. This type of paradigm shift with consequent benefits also mirrors issues raised in the international arena in relation to school science teaching (Rocard et al., 2007) and, significantly, the current study provides a possible means by which to support such change.

Furthermore, the methodologies were not merely rehearsed or repeated by teachers following on from CPD, but in many cases the CPD appeared to have changed the teachers' whole view of how science teaching should be done. Significant changes in teaching practices had occurred with all the participating teachers and for some, at least, these were rooted in a change of viewpoint about the purpose and significance of an investigative culture in the classroom. The teachers also reported greater professional confidence and use of group work. The benefit in terms of teachers' enhanced confidence with using IBSE in classroom practice is a significant outcome of this study.

The enhancement of dialogical skills reported by the teachers as a consequence of implementing the CPD methodologies to science teaching is especially encouraging in the light of recent requirements in Ireland for primary teachers to devote additional weekly time to these core skills (DES, 2012). In a primary curriculum that is perceived to be overloaded (NCCA, 2008), this could lead to a

reduction in time allocated to other subjects such as science. It is our contention that utilising inquiries *in* and *about* science has the potential to promote genuine integration of oral language objectives from the English curriculum (DES, 1999b), whilst still affording the recommended amount of time for teaching science. Whilst inquiry-based focus of this science CPD programme appears to link to significant impact on the teachers in the current study, the model for the CPD should also be acknowledged as being key to the effectiveness of the CPD.

Teachers in the study pointed to a number of aspects of the CPD model, which they perceived to be beneficial. These were in general, the same ones identified in the research literature (Darling-Hammond et al., 2009; Desimone, 2009; Guskey, 2003; Loucks-Horsley et al., 2009) as significant factors of effective professional development design, namely: active participation; reflective practice; collaboration and duration of programme. The authors attribute the positive findings of the present study to the careful design and implementation of the professional development programme. The success of the programme was likely due to the fact that the model drew together the core features identified as fundamental for successful professional development and good teaching (Desimone, 2009) and adapted them to the needs of the participants. The programme provided teachers with opportunities to engage in a range of inquiry-based activities that their pupils would subsequently experience i.e. the programme modelled the approach to teaching and learning that teachers were then expected to carry out in their classrooms. Such an approach provided the teachers to shape and pace activities and discussions to suit their individual needs (Smith, 2013). According to Bandura (2000) if teachers actively engage in application of skills and knowledge during their own learning, they are more likely to implement the skills and knowledge in their classrooms.

The collaboration in particular appears to have gone beyond the interactions initially envisaged by the authors in recruiting at least two teachers from each of the participating schools. Teachers asserted that they had collaborated with their “partner” teachers. In some cases, participating teachers also took the initiative to become facilitators for CPD within their own schools (Hogan et al., 2007), which is testament to their enhanced confidence as classroom practitioners of science. Once the teachers established a trust and rapport amongst themselves and with the authors, the majority of them engaged in in-depth open pedagogical dialogue and critical reflection. Pritchard and McDiarmid (2005) argue that reflective practice is a key feature needed for effective teaching and professional development. Participants also developed informal networks within the group as a whole, which extended beyond the discussions in the CPD workshops (Hord, 2009). Such networking with colleagues offered the participants different learning experiences that they could not obtain from expert-led activities.

Teachers also spoke positively about the duration of the CPD, in particular the fact that it afforded them opportunities to try out new ideas and then gain feedback in subsequent sessions. Duration of CPD has been noted previously as a key factor in effective CPD provision for science education (Ingvarson, Meiers, & Beavis, 2005; Supovitz & Turner, 2000). The on-going nature of the programme afforded the participating teachers the opportunities and time to develop their pedagogical and content knowledge and capacities to critically reflect on their teaching practice, with a view to bringing about change in their classroom practice. Such opportunities concentrated on key issues and happenings in the teachers’ experiences of teaching science and relating these to important insights from the research literature associated with teaching practice. Although the exit interviews were held some months after the completion of the CPD, it remains to be seen whether these apparently substantial changes in practice and professional enhancement continue in the longer term.

The selection of participants for the programme could be viewed as a potential limitation of the study. This confined the study to limited geographical locations. However, examination of the participants (Table 1) shows that they by and large reflect the general teacher population in terms of qualifications, gender and teaching experience. A second limitation of the study could be that the data were gathered immediately at the end of the second year of the programme. A follow-up study that would examine the extent to which these teachers are still utilising the CPD methodologies and

whether they continue to hold positive attitudes towards teaching science a number of years after the CPD would reveal the true impact the CPD has had on these teachers' practices in teaching science.

It is evident that this group of teachers has been affected in a range of positive ways by their experiences of this CPD programme. It is acknowledged that this study was only conducted on a small scale, albeit over a lengthy timeframe. However, the authors consider that the evidence for depth of change is sufficient to warrant the development of CPD courses for other teachers (nationally and internationally) of a type and content similar to that described in the present study.

The current study was aimed at remediating some of the concerns regarding the teaching of primary science in Ireland in that it endeavoured to develop teachers' pedagogical knowledge in teaching *about* science through inquiry so that they would develop the requisite pedagogical knowledge and skills and confidence to implement the PSC using its intended methodologies (DES, 1999a). The findings have shown that engagement with and reflection on different methodologies for teaching *about* science through inquiry has had a positive impact, with all 17 teachers in this study reporting that they now; teach science more frequently; include NoS content in their science lessons; employ inquiry-based methodologies when teaching the PSC; and have more confidence in teaching science. It would appear important, therefore, that curriculum advisors and developers recognise the apparent benefits of developing teachers' pedagogical knowledge in teaching *about* science through inquiry on developing teachers' confidence in employing more inquiry-based approaches to teaching primary science.

Even though this was a small-scale study the authors believe that it has important implications for professional development in primary science in Ireland and internationally. The findings of this study also reveal that the programme can be characterised as effective using three steps of Desimone's (2009) core conceptual framework. Teachers identified Desimone's core features as fundamental for successful professional development and good teaching (step 1). The results also demonstrated that the teachers' participation had a positive impact on their science knowledge and attitudes to teaching science (step 2) and classroom practice (step 3). Further research within the present study will attend to step 4 of Desimone's model—investigating pupils' attitudes to school science changed as a result of their teachers' participation in the programme (step 4).

A key challenge for professional development providers in the future is investment in the development of a system of high-quality professional development in the area of primary science. Features of effective professional development such as those proposed by Desimone (2009) could be used as a framework when planning future models of professional development. At present in Ireland professional development is mainly concerned with achieving the needs of the system. According to O'Sullivan, McMillan, and McConnell (2011) "it is about building teacher skills rather than capacity. The focus is on curricular change rather than developing the person of the teacher" (p. 8). There is a need for a more balanced approach between professional development that supports the needs of the individual teacher and that of the system. The results of this study suggest that the model used can lay the fundamentals for effective alternative models of professional development.

The model used in the present study was successful in the context of primary science in Ireland. The main features of this model are broad enough to be tailored globally, particularly in other countries where inquiry-based experiences form core pedagogies.

Acknowledgements

The researchers would like to thank all the teachers who took part in the Fibonacci Project in Dublin. It was a pleasure working with you.

Funding

This research was conducted during the Fibonacci Project which was funded by the EU commission under the FP7 Framework.

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Citation information

Cite this article as: Changing practice: An evaluation of the impact of a nature of science inquiry-based professional development programme on primary teachers, Cliona Murphy, Greg Smith, Janet Varley & Özge Razi, *Cogent Education* (2015), 2: 1077692.

Note

1. The teacher put "THEY" in capitals for emphasis in her reflective journal.

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