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An innovative model of professional development to enhance the teaching and learning of primary science in Irish schools

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This study investigates the influence of a two-year professional development programme on primary teachers' attitudes towards primary science, their confidence and competence in teaching science, and pupils' attitudes towards school science. Unlike the traditional 'one-size-fits all' model of professional development, the model developed for this study, carried out in Ireland, is ongoing and gives teachers opportunities to collaborate with their colleagues, sharing practices and knowledge, to reflect on their pedagogic practice, to focus on pupil learning and to be involved in decision-making. This article explores the relationship, if any, between teacher involvement in a sustained, collaborative professional development programme, their confidence and competence in teaching science and their classroom practice. Findings from this study have shown that the participants become substantially more confident and competent in teaching primary science. Most significantly, teachers have made dramatic changes to the way they teach science, resulting in their pupils becoming more positive and motivated to learn science.

Keywords: primary science; teacher professional development; teachers' confidence; teachers' competence

Introduction

International research (for example, Harlen and Holroyd 1997, Goodrum *et al*. 2001, Appleton 2003, Murphy *et al*. 2007) has identified primary teachers' confidence, competence and attitudes towards teaching science as challenges to the effective teaching of science at primary level. Jarvis and Pell (2004) demonstrated that many primary teachers not only lack confidence and competence to teach science, but they also possess an incomplete understanding of science concepts. Many of the teachers' ideas are comparable with the 'misconceptions' or 'alternative conceptions' generally held by children and were likely to give misleading information in an effort to explain science to their pupils (Osborne and Simon 1996). Teachers with low self-confidence and/or poor science content knowledge tend to use teaching strategies that avoid engaging pupils in science or avoid teaching science altogether (Osborne and Simon 1996, Harlen and Holroyd 1997, Appleton and Kindt 1999). Tobin *et al*. (1994) illustrate that teachers' attitudes toward science teaching are a vital factor in determining the quality of their

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classroom practice. Many primary science teachers can have negative attitudes towards teaching science, stemming from factors such as they did not study it in school, negative experiences of science in their own education and lack of confidence and/or competence in teaching it.

The literature on how to improve the teaching of primary science focuses in particular on support in the form of professional development, improving teacher confidence and competence. Good-quality continuing professional development (CPD) is considered key to improving primary teacher confidence in nearly all aspects of science teaching (Murphy *et al*. 2005).

The current article highlights some of the salient features of a recent professional development project on primary science carried out in Ireland. It is concerned with investigating the impact of the programme on the teachers' confidence and competence teaching science and also on their classroom practice. More specifically, the article addresses the following three research questions:

- What changes (if any) in teachers' confidence in teaching science and competence in relation to knowledge of the science curriculum occurred during the study?
- What changes (if any) in teachers' classroom practice occurred during the study?
- What aspects of the intervention programme promoted teachers' subject confidence, competence and attitudes?

Professional development

A review of the professional development literature demonstrates considerable criticism of 'traditional' forms such as 'one-off' workshops or short modular courses for failing to have a lasting impact on classroom practice (Hawley and Valli 1999, Guskey 2002, Hoban 2002). The traditional approach to professional development tends to be a one-step approach to teacher learning: 'that promotes a conception of teaching as a "craft" with a mastery resulting from the progressive accumulation of knowledge and skills' (Hoban 2002, p. 21). The strength of this approach is that it gives teachers a deeper understanding of what they already know, and presents knowledge that is worth replicating, in a convenient and economical way. However, it does not consider the context of the school, resistance and 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 literature illustrating the various characteristics of high-quality professional development needed to improve teaching. Research studies have indicated a number of characteristics that are needed to improve the quality and success of professional development:

- Enhance teachers' content knowledge and pedagogical knowledge (Cohen and Hill 1997, Kennedy 1998).
- Be ongoing and sustained (Supovitz and Turner 2000, Garet *et al*. 2001).
- Involve active engagement on the part of the participants (Hawley and Valli 1999).
- Be job-embedded (Loucks-Horsley *et al.* 2003).
- Be collaborative and collegial in nature (Hord 2009).

These characteristics have profoundly shaped the structure and implementation of the model of professional development in the present study. As well as enhancing teachers' knowledge and skills, they also give an insight and understanding of the participants and processes that make up an effective professional development programme. These characteristics suggest that professional development is more than a sequence of isolated workshops or in-service days; rather, it is a process of putting knowledge into practice within a community of actively engaged practitioners.

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 Department of Education and Skills. These are primarily introduced following a change in curriculum and/or to address topics relevant to individual subject syllabi, and generally teachers are not given time to incorporate knowledge and skills acquired at workshops into their classroom practice (Malone and Smith 2010, p. 108). Leonard (1996) claims the main aim of such courses is to give participants information and resources in a top-down manner with the intention of implementing central decisions. A report commissioned by the Teaching Council of Ireland (2009) to inform discussions and policy formation on teacher education in Ireland found that, even with the progress in professional development provision over the last decade, this provision is still generally short-term, once-off and not as connected to teachers' professional practice as it should be (2009, p. 201). An OECD (2009) Teaching and Learning International Survey (TALIS) indicated that the professional development programmes attended by Irish teachers largely relate to implementation of national curriculum programmes, with little prominence given to the professional development needs of individual teachers. Granville (2005, p. 58) contends that the concept of CPD is well established in policy rhetoric but less well established in practice at the level of the teacher and the school. Unfortunately, many teachers' perceptions of what activities make up professional development are often restricted to attendance at workshops and short modular courses, and seen as a separate 'add on' to the job (Hogan *et al*. 2007).

Evaluation

Commentators (Guskey 2002, Piggot-Irvine 2006, Rose and Reynolds 2006) argue that, traditionally, educators have not paid much attention to evaluating their own professional development efforts. Rose and Reynolds (2006, p. 222) claim that, '… the impact of CPD is rarely assessed over the long term, and is often based on self-reports by teachers of the CPD experience itself, rather than the outcome'. Piggot-Irvine (2006, p. 486) identifies a number of features needed for the effective evaluation of professional development programmes:

- Devising evaluation expectations before the programme is implemented.
- Incorporating evaluation expectations within the professional development plan.
- Using rigorous data-based information to ascertain the effectiveness of the programme.
- Establishing whether attitudes and practices of participants have changed for the better.
- Determining whether the changes are manifest in classroom and school practices.

In the Irish context, Hyland and Hanafin (1997) highlight the lack of published evaluations of professional development programmes. Malone and Smith (2010) stress that evaluation of professional development is generally summative in nature, occurring immediately after a workshop. In addressing this challenge, the present study incorporates all five elements proposed by Piggot-Irvine and Guskey's (2000) model of evaluation, which consists of evaluation at five levels: participants' reaction; participants' learning; organisational support and change; participants' use of new skills and knowledge; and pupil learning outcomes.

The intervention model

The study being reviewed in this article was organised by the Biology Education Department of St Patrick's College, Dublin City University. It was a research project of two years' duration co-funded by the Irish American Partnership and the Irish Government Department of Education and Skills. Called the Western Seaboard Science Project (WSSP), the study was conducted in 15 small rural primary schools (two/three teachers) in the west and north-west of Ireland. The schools were grouped into three clusters of five schools. The sample population consisted of 24 practising teachers and 281 pupils. All of the participating teachers consented to take part in the research study as well as the professional development programme. The participating pupils were drawn from fourth, fifth and sixth classes (multigrade) with an age range of 9–12 years (the final three years of primary school in Ireland).

The main aims of the model were to bring about progressive changes in: teachers' science content knowledge; teachers' classroom practice; teachers' attitudes to science; and pupils' attitudes to learning science (Garet *et al*. 2001, Guskey 2003, Loucks-Horsley *et al*. 2003). Defining features of the programme (Hogan *et al*. 2007) included an emphasis on the following:

- *Active participation* – workshops were of an interactive nature, they were designed and facilitated by the researcher, in ongoing discussion with the participants. Participants were encouraged to take an active and responsible role in the design of the workshops.
- *Meaningful collaboration* – a central element of the programme was the building up of trust between the participants as a group, and with the researcher. Teachers were encouraged to share their knowledge and ideas on teaching and learning processes centred on their own experiences. This was encouraged and facilitated using a variety of strategies such as sharing resources and ideas, discussing pedagogic practice and access to a virtual learning environment ('Moodle').
- *Continuity* – the programme was designed as planned events within an ongoing sequence (over two years), as distinct from being 'once-off' events carried out at irregular intervals. Each workshop had specific contributions to make to the ongoing development of particular capacities on the part of the participants and responded to the individual needs of the participants as they arose.
- *Feedback* – included was: feedback from the participants to the workshop facilitator (researcher) after each workshop; feedback (evaluation) to the researcher mid-way through the programme and at the end of the programme; and feedback by participants to workshop colleagues during the workshop

and between workshops (using a virtual learning environment), concerning teaching and learning initiatives being carried out by them in their own classrooms. Teachers were encouraged (not obliged) to: critically reflect on new knowledge and skills they acquired at workshops; carry out action research in their classrooms on the impact of these on their classroom practice; and document their findings for discussion with colleagues at the next workshop. The action research projects were deliberately coupled to the various themes explored at the workshops.

Nature of workshops

The WSSP programme was made up of 12 three-hour workshops over a two-year period (October 2008–June 2010). The workshops were designed and delivered by the researcher, in ongoing consultation with the participants. Between workshops the researcher provided ongoing support to participants, such as regular visits to individual teachers in their schools (when requested), a virtual learning environment (Moodle), emails and telephone conversations. Visits to schools were intended to help teachers in their efforts to implement in their classrooms new strategies explored at the workshops.

As the programme progressed, the researcher acted as a 'Critical Friend' (Costa and Kallick 1993) to the participants, encouraging them to engage in professional pedagogical dialogue and to critically review their own classroom practice.

Principles underlying the workshop approach are listed as follows:

(1) The learner constructs meaning and deep understanding through experience. Research by Radford (1998) demonstrates that pupils learn best when they are actively engaged in their own learning. The WSSP programme allowed teachers to experience the same content, methods and activities that their pupils were expected to learn in schools. By experiencing the procedures for themselves, teachers are better prepared to help pupils become active, engaged learners (Radford 1998).
(2) New knowledge is built on previous learning and experience. The programme encouraged teachers to integrate what they were learning into what they already knew and challenged their previous understanding that was not in agreement with scientific explanations (cognitive conflict). This was carried out in a context that was real, relevant and considered the capacities of all the participating teachers.
(3) The programme encouraged teachers to advance effective teaching and pupil learning by providing them with a range of knowledge bases – science content, pedagogy and learning theories.
(4) Pursued issues that were relevant to the classroom experience of the participants. Over the two years of the programme, participants were involved in shaping its content and direction: 'a sense of ownership is a vital element in creating a supportive environment for teachers' (Callan 2006, p. 117). From the very beginning, teachers were encouraged to indicate their preferences for workshop topics and the format of the workshops.

Workshop content varied from workshop to workshop in response to teachers' stated needs and included some or all of the following elements:

- Teacher engagement in a number of hands-on science activities.
- Teachers reflecting on their understanding of basic science concepts found in the primary science curriculum, in the context of children's ideas.
- Introduction of innovative inquiry-based teaching methodologies.
- Teacher feedback to researcher and participants on science tasks carried out with their pupils in between workshops.
- Teacher discussions related to their experience of teaching science.
- Use of information communication technology (ICT) in the classroom and introduction to a virtual learning environment (Moodle).

Methodology

Owing to the nature of the research questions, a mixed-methods approach involving elements of empirical research and investigative forms of qualitative research was deemed the most appropriate approach to this study. Johnson and Onwuegbuzie (2004, p. 15) suggest that a mixed-methods approach, 'allows researchers to mix and match design components that offer the best chance of answering their specific research questions'. Multiple data sources were used in this study, providing for triangulation of the findings and enhancing the validity and credibility of the research (Denscombe 2003).

To ascertain whether changes uncovered were as a result of the professional development initiatives, data from the teachers were collected before and after their participation in the professional development programme. The data were gathered using four instruments:

(1) Pre-intervention and post-intervention teacher questionnaires.
(2) Post-intervention teacher interviews.
(3) Pre-intervention and post-intervention assessment of teachers' understanding of key science concepts.
(4) Monitoring project development – informal classroom-based observations and reflection sheets.

Questionnaire (pre/post intervention)

The measurement scales for the main parts of this questionnaire were adapted from Pell and Jarvis (2003) and consisted of a five-point Likert-type scale for each subject. The questionnaire was broken up into two main parts in order to obtain various types of information. Part one asked teachers to provide personal information that could have some influence on their attitudes towards science, including gender, teaching experience and qualification in science. The second part of the questionnaire was designed to gather information relating to teacher confidence: in teaching science as well as other subject areas of the primary curriculum; in teaching different aspects of the primary science curriculum; and in their own science teaching skills and using inquiry-based teaching methodologies in science lessons. The pre-intervention questionnaires were administered in October 2008 and the post-intervention questionnaires were administered at the final workshop in June 2010.

Interviews

Three separate semi-structured group interviews (one for each cluster) took place at the end of the final workshop in June 2010. The interview protocol consisted

primarily of open-ended questions that involved in-depth probing of teachers' perceptions of the intervention programme and its impact on their teaching beliefs and teaching practice. The interview schedule was divided into two parts. The first part was concerned with determining the impact of the intervention programme on classroom practice. The second part explored teachers' thoughts, opinions and impressions about the WSSP model of professional development and their previous experience of professional development. Only 15 of the 24 participating teachers were interviewed. These were selected because they were teaching the pupils of fourth, fifth, and sixth classes over the duration of the project. Each interview lasted between 30 and 40 minutes. Interviews were audiotaped and then transcribed verbatim.

Teacher understanding of science concepts

Participating teachers were given a science cognitive test prior to the intervention programme (September 2008) and post intervention (June 2010). This was to find out their ideas about key science concepts in the primary science curriculum and to discover whether or not they held misconceptions regarding these concepts. Questions used were adapted from Matthews and McKenna's (1996) study of pre-service primary teachers' understanding of basic science concepts and were written to ensure compatibility with the requirements of the primary science curriculum. Because of the multi-grade nature of the schools involved in this study, no standard measure of science subject matter was taken from the pupils who participated.

Monitoring project development

In addition to carrying out pre/post-intervention questionnaires and interviews, there was provision for building in new features during the actual implementation of the research. At the start of the intervention programme the researcher visited the participants in all 15 schools, enabling the researcher to see the 'real-life' classroom environment. To investigate the benefits, challenges and impact of the programme on their classroom practice and their pupils' learning, teachers in the 15 schools were asked to complete reflection templates at the end of every workshop and an open-ended reflection template at the end of Year One. The researcher also visited three schools (one from each cluster) on three occasions: at the beginning, middle and end of the WSSP programme. Informal observations were organised to allow the researcher to observe the complete science lesson. The researcher took detailed field notes. Informal to observation allows the researcher the opportunity 'to see what there is to see without the blinders of hypothesis' (Patton 2002, p. 278) and to observe the complexity of the situation to be considered, and allows the observer considerable freedom in what information is gathered and how it is recorded (Robson 2002).

Data analysis

The responses to the closed questions on the questionnaire were analysed statistically using SPSS version 15. Parametric paired-sample *t*-tests were carried out to determine the impact that the programme had on teachers' confidence and attitudes to teaching science. Qualitative data gathered from the interviews and reflection

template (end of Year One) were analysed and coded into thematic categories. This involved several rounds of reading data, identifying concepts embedded within the data, organising discrete concepts into categories and linking them to broad themes. The researcher and a colleague coded the interview transcripts to provide inter-rater reliability. Qualitative findings were used to corroborate those obtained from the questionnaires.

Results

Results are based on statistical analysis of teachers' self-rating on the pre-intervention and post-intervention questionnaires, on analysis of teachers' understanding of science concepts (pre/post) and on qualitative analysis of interviews and participants' written responses on the open-ended reflection templates (at end of Year One).

Research question 1: teachers' confidence and competence in teaching science

Teachers were asked to rate their confidence, on a five-point Likert scale, in teaching English, Irish, history, mathematics, geography and science. Table 1 shows the mean rating score for confidence in each of these subjects pre intervention and post intervention.

Pre intervention, teachers were far more confident in teaching English, Irish, history, mathematics and geography than science. Post-intervention findings show that there was a statistically significant increase ($p < 0.01$) in teachers' confidence in teaching science (from a mean of 3.23 to a mean of 4.05). This finding shows that teachers' confidence in teaching science moved from an average level of confidence to a high level of confidence; that is, from a level where teachers are capable of teaching science to a substantively more self-assured level. Most importantly, it shows that teachers' confidence in teaching science no longer differed greatly from their confidence in the teaching of other subjects.

Teacher confidence in teaching the content of science curriculum

Teachers were also asked to rate their confidence teaching the four different content strands of the curriculum on a five-point Likert scale. Table 2 shows the mean rating score for teachers' perceived confidence in teaching each of the selected content areas pre and post intervention. Pre intervention, teachers had high mean scores

Table 1. Changes in teachers' confidence across six subject areas (pre and post intervention).

	Pre intervention ($n = 24$)		Post intervention ($n = 22$)		
Subject	Mean	Standard deviation	Mean	Standard deviation	Significance
English	4.50	0.598	4.55	0.510	0.665
Irish	4.23	0.813	4.32	0.646	0.427
History	4.41	0.734	4.50	0.512	0.427
Geography	4.41	0.734	4.50	0.598	0.492
Mathematics	4.41	0.590	4.45	0.596	0.665
Science	3.23	0.869	4.05**	0.486	0.000

Notes: **$p < 0.01$. 1 = very low confidence ('I require help with this'); 2 = low confidence; 3 = average confidence; 4 = high confidence; 5 = very high confidence ('I have no problem with this').

Table 2. Teachers' perceived confidence in teaching content of primary science curriculum (pre and post intervention).

Content	Pre intervention (n = 24) Mean	Pre intervention (n = 24) Standard deviation	Post intervention (n = 22) Mean	Post intervention (n = 22) Standard deviation	Significance
Living Things					
Structure of some of the body's major internal and external organs	3.91	1.005	4.23	0.869	0.031
Reproductive systems of both males and females and physical changes in both	3.45	1.011	3.73	0.883	0.030
Some of the factors that affect plant growth	3.77	0.922	4.00	0.873	0.021
Some of the ways plants reproduce	3.64	1.002	4.05	0.722	0.016
Energy and Forces					
The refraction of light using mirrors	3.00	0.976	3.55**	0.671	0.004
The splitting and mixing of light	2.86	1.037	3.55**	0.912	0.001
How sound travels through materials	3.05	1.133	3.91**	0.684	0.000
How sound is produced	3.14	0.990	4.09**	0.750	0.000
Sources of heat	3.41	0.959	3.95**	0.844	0.002
Transfer of heat (conduction, convection and radiation)	3.23	1.006	3.95**	0.899	0.000
Electrical current and construction of simple circuits (e.g. lamps, buzzers, motors)	3.05	1.495	4.00**	0.976	0.001
Electrical energy	3.00	1.234	3.91**	0.811	0.000
Magnets and their push and pull effects	3.77	1.193	4.09	0.868	0.069
The making of magnets	2.86	1.082	3.64**	0.953	0.002
The effect of friction on movement	3.27	1.120	4.05**	0.785	0.000
The force of gravity	3.09	0.921	4.00**	0.756	0.000
Materials					
The effects of heating and cooling on a range of solids, liquids and gases	3.23	0.869	3.68**	0.780	0.002
How a wide range of materials may be changed by mixing	3.18	1.006	3.50	0.913	0.090
Environment					
The effects of human activity on the environment	4.09	0.921	4.41	0.666	0.069
The need to conserve resources	4.14	0.889	4.45	0.596	0.069

Notes: **$p < 0.01$. 1 = very low confidence ('I require help with this'); 2 = low confidence; 3 = average confidence; 4 = high confidence; 5 = very high confidence ('I have no problem with this').

(average to high confidence level) regarding teaching about Living Things and Environmental Awareness, and they were reasonably confident (average confidence level) teaching about Materials. However, they had low to average levels of confidence teaching about Energy and Forces. In general, teachers' perceived confidence in physical science items was lower than that in biological science items.

Post intervention, there was a statistically significant improvement ($p < 0.01$) in teacher confidence in 12 of the 20 questions asked. All 12 questions were

concerned with the physical science content of the curriculum. Teachers became much more confident with a number of the more conceptually challenging physical science topics. For example, for topics such as 'the force of gravity' and 'the effect of friction on movement', teachers' confidence levels moved from an average level to a high level of confidence. This is an important finding, again showing that advances of considerable magnitude in teachers' confidence in teaching challenging physical science topics were made. This result is particularly significant as the programme placed a strong emphasis on physical science topics, especially those that had been perceived as difficult by the participants.

Teachers' confidence in their own science teaching skills

Teachers were asked how confident they felt regarding their own science teaching skills in science lessons. Table 3 shows the mean rating score for confidence in teachers' deployment of teaching skills, pre intervention and post intervention.

Pre intervention, teachers' confidence in their own science teaching skills was uncertain (low average confidence level), especially in areas such as 'encouraging children to try out their own ideas in investigations', 'encouraging pupils to think for themselves' and 'deciding what science skills are to be developed in an activity'. Post intervention, there was a statistically significant improvement in teachers' confidence ($p < 0.01$) in their own science teaching skills in six of the eight questions asked. For three items – 'using questioning as a tool in science teaching', 'explaining science concepts to pupils' and 'encouraging pupils to think for themselves' – teachers' confidence level moved from an average confidence level to a high confidence level; from a level where teachers are capable of teaching science to a substantively more self-assured level.

Table 3. Teachers' confidence in their own science teaching skills (pre and post intervention).

	Pre intervention ($n = 24$)		Post intervention ($n = 22$)		
Skill	Mean	Standard deviation	Mean	Standard deviation	Significance
Using questioning as a tool in science teaching	3.77	1.02	4.50**	0.598	0.002
Explaining science concepts to pupils	3.77	0.869	4.14**	0.774	0.002
Encourage children to try out own ideas in investigations	3.09	0.894	3.91**	0.750	0.000
Encourage pupils to think for themselves	3.32	0.796	4.00**	0.617	0.009
Organising and delivering practical work	3.59	0.733	3.73**	0.631	0.001
Deciding science skills to be developed in an activity	3.09	0.610	3.50**	0.598	0.004
Using ICT to enhance teaching and learning science	2.86	0.941	3.05	0.844	0.162
Assessing practical work	3.59	0.854	3.77	0.752	0.162

Notes: * $p < 0.01$. 1 = very low confidence ('I require help with this'); 2 = low confidence; 3 = average confidence; 4 = high confidence; 5 = very high confidence ('I have no problem with this').

Evidence of an increase in teachers' confidence in teaching science is evident from interview comments made by the participants. All 15 teachers interviewed stated that their confidence in teaching science had improved as a result of their participation in the programme. Teachers identified a number of areas that helped to create this change, including appreciation of the practical nature of science, understanding of science concepts and trying different approaches to teaching science. The following comments are representative of their views: 'I have picked up a lot of science at these workshops, theory and practice. I am now more confident, I know what is happening in the science lessons' and 'What we do here [workshops] in the hands-on work is very simple, I can ask questions on the activities, this gives me more confidence to go back to my children and try it with them'.

Teacher competence and understanding of basic science concepts

Pre and post intervention, participants were presented with a series of short questions to investigate their understanding of basic science concepts found in the primary science curriculum. Table 4 shows that prior to intervention many of the teachers had misconceptions in a number of key areas, especially Forces and Electricity. These responses point to a telling lack of knowledge and understanding of basic concepts needed to teach science effectively.

Post intervention, there was a dramatic increase in the number of teachers who gave correct answers to the questions, especially in the physical science area; for example, teachers' understanding of how electricity moves was poor prior to their involvement in the intervention programme. Only 26% of the teachers disagreed with the statement 'less current returns to the battery when it passes through a bulb' (many of them believing it was used up). Post intervention, this changed to 89%. Many teachers had problems understanding gravity. Prior to intervention, only 68% of teachers disagreed with the statement 'gravity only acts on objects when they are falling'. At the end of the intervention this changed to 95%. It is apparent from examination of the pre-test and post-test scores that there was a decisive improvement in teachers' scientific content knowledge in all questions where there could be improvement. As none of the participants were involved in any other science professional development while participating in the intervention programme, these results confirm that the intervention programme addressed some of the long-standing deficiencies.

All 15 participants interviewed stated that they felt more competent teaching science as a result of their involvement in the project. Teachers identified two main areas that helped to bring about this change: appreciation of the practical nature of science; and understanding of science concepts. One participant stated:

> when we did open-ended investigations on sound in the workshop … I went back to school set them up with my pupils … I knew exactly what to do … I even knew most of the answers to the questions they asked me; the reason being their questions were more or less the same as the questions I asked when doing the investigation at the workshop …

Another commented:

> when I started the workshops I did not feel competent about the way I taught science, my knowledge of science was at a very low ebb, it has really improved and I put this down to the discussions, hands-on activities and my enjoyment at the workshops.

Table 4. Percentages of teachers responding correctly to questions of basic science concepts (before and after intervention programme).

Statements (true or false)	Pre intervention (% correct)	Post intervention (% correct)	Change (+/–)
Gravity only acts on objects when they are falling	68	95	+
Friction only acts on moving objects	53	89	+
Heavy things fall to the ground quicker than light things	21	100	+
Objects that are sitting still have no forces acting on them	100	100	
The moon is luminous	63	100	+
Sound only travels through air, not solid objects or liquids	95	100	+
You only hear when you listen	95	100	+
Higher notes are louder than low notes	63	89	+
Sound makes vibrations	53	84	+
Less current returns to the battery when it passes through say a bulb (it is used up)	26	89	+
Current flows from battery to bulb but not from bulb back to battery	53	100	+
Gases do not have mass	84	100	+
If an object is at rest no forces are acting on it	95	100	+
Wood floats and metal sinks	58	100	+
All metals are attracted to a magnet	69	100	+
Heat travels from a cold body to a hot body	74	100	+
If two objects have the same temperature then they have the same amount of heat	68	95	+
Correct drawing of how we see light (two lines with arrows)	47	100	+
Which of the following are plants?			
A tree in the ground	89	100	+
A potato growing in the ground	68	100	+
A daisy growing in the ground	84	100	+
A thistle growing in the ground	84	100	+
Which of the following are animals?			
A fish in a pond	58	100	+
A dog found around the house	100	100	
A human being	89	100	+
A common household fly	58	100	+
A snake	63	100	+
A spider	68	100	+

Early visits to all three schools indicated teachers engaged in didactic approaches to teaching science (i.e. whole-class activities, subject-based teaching), where the focus of control lies with the teacher and the pupil having a more passive role in learning (Varley *et al*. 2008). There was little evidence of pupils engaging in open-ended investigations on their own. Teachers did not give their pupils opportunities to develop and test their ideas. However, by the end of the programme a number of classroom changes were observed. For example, teachers were involving their pupils in various open-ended investigations, placing less emphasis on instructions and engaging their pupils in problem-solving and higher-order thinking. There were more scientific discussions during hands-on activities.

Research question 2: changes in teachers' classroom practice

Analysis of pre-intervention and post-intervention data indicates that the programme had a positive impact on teachers' instructional practice. For example, using a five-point Likert scale teachers were asked how often they used innovative teaching methodologies in science lessons. Table 5 shows the mean rating score for confidence in teacher deployment of innovative teaching approaches, pre intervention and post intervention.

Pre intervention, teachers seldom used innovative teaching methodologies such as concept cartoons, concept maps, written feedback on assessment work or ICT in their science lessons. Post intervention, there was a statistically significant improvement ($p < 0.01$) in six of the 10 questions asked. Close inspection of the results shows that for the items 'predict–observe–explain' and 'using children's ideas to start a topic', teachers moved from 'sometimes' to 'frequently' using them in science class. For the items 'concept mapping' and 'using ICT', teachers moved from 'rarely' to 'sometimes' using them in lessons. The most significant finding concerned concept cartoons: it showed a move across two levels; that is, teachers moved from 'not at all' to 'frequently' – from a mean score of 1.59 to 3.41. These findings clearly illustrate that the intervention programme provided some new ideas that the teachers found useful, willingly engaged with and incorporated into their classroom practices.

All 15 teachers interviewed indicated that the project had a positive impact on the way they teach science. Their responses to this question suggested two main types of change in their teaching approach: more hands-on activities and more systematic pedagogical thinking. Eight of the 15 participants indicated that the greatest change in teaching science for them was the stronger emphasis on more open-ended practical work with their pupils. Their responses indicated the significance of involving the children more in hands-on science and encouraging them to find out for themselves, rather than being told the answers by the teacher. The following comments capture this very well:

Table 5. How often teachers used innovative teaching methodologies (pre and post intervention).

	Pre intervention ($n = 24$)		Post intervention ($n = 22$)		
	Mean	Standard deviation	Mean	Standard deviation	Significance
Teacher questions	4.23	0.813	4.68**	0.646	0.009
Cooperative learning	3.59	1.098	4.14	0.774	0.015
Predict–observe–explain	3.23	1.343	4.14**	0.889	0.008
Concept cartoons	1.59	0.734	3.41**	1.098	0.000
Concept mapping	2.23	1.110	3.18**	0.958	0.001
Discussion in class	4.09	0.921	4.41	0.908	0.016
Using children's ideas to start a topic	3.41	1.007	3.50**	1.058	0.000
Using hands-on science	2.27	0.921	3.52**	0.664	0.110
Using ICT	2.64	1.217	3.05**	0.999	0.004
Written feedback	2.14	1.082	2.73	0.935	0.029

Notes: **$p < 0.01$. 1 = not at all; 2 = rarely; 3 = sometimes; 4 = frequently; 5 = very frequently.

> you must involve the children more, they must get more hands on, move away [the teacher] from the chalk and talk approach to teaching science.

> [Prior to project] I used textbooks a lot … when you experience the practical side of it [science at workshop] you are more confident going back to class … pupils enjoy it and they build up a camaraderie of working together.

Five of the 15 teachers stressed in particular how the project encouraged them to actively reflect and reformulate their pedagogical thinking. One stated:

> before I started here [workshops] I would not think about different ways I could teach science lessons … now I think more about the methodologies … I think in advance of how I am going to do it [science lesson] and how to avoid the pitfalls.

Another teacher voiced a new awareness of the importance of probing children's ideas at the beginning and end of a science lesson: 'concept cartoons are a fabulous idea for finding out children's ideas before a lesson or after a lesson for revision'. The majority of teachers in each cluster group were in agreement with these comments. These encouraging findings illustrate the kinds of shifts in professional thinking and action that the workshops promoted among the participating practitioners.

It is also evident from all teachers' written responses to the open-ended reflection template (end of Year One) that their teaching practice changed as a result of their involvement in the project. They identified two main areas of change: greater use of hands-on science activities (11 respondents) and a more pupil-centred approach to teaching (four respondents). These changes are most tellingly illustrated by some of the written comments of teachers, including: 'I don't avoid science topics I am unsure about anymore … I give more time to hands-on experiments and more time for discussion' and 'yes, I have moved away from the theory and book learning, the children are learning much more through discovery and investigations'.

Research question 3: what aspects of the intervention programme promoted teachers' subject confidence, competence and attitudes?

The most frequently discussed themes regarding this question included: duration of the professional development, relevance of the professional development and collaboration; that is, specific features found in the WSSP model.

Participants indicated that other professional courses they had attended prior to this programme were too short in duration and too overloaded with information. As one teacher put it: 'when the new curriculum was introduced [2003] it was one long day [in-service], everything was thrown at you like a wall and a lot of what was thrown did not stick'. There was a strong consensus that the traditional type of in-service courses they had experienced did not allow them the opportunity to return to their classrooms to try out what they had learnt, or to discuss their practice at follow-up workshops. Significantly, all participants spoke favourably of the WSSP model in terms of providing more welcome forms of CPD. The following comments clearly illustrate this: 'This [current model] has a long-term approach and it is certainly superior to the short sharp shock approach' and 'Now that it [in-service] is coming at you in small manageable bits, more of it is sticking … you get a chance to implement it straight away'.

Six respondents from across the three clusters specified that they were overloaded with content at other professional development courses they had attended. They stated a preference for the approach used by WSSP (i.e. less in-depth science content and more hands-on experience), allowing them the opportunity to take what they learnt in the workshops back to their classroom to try it out with their pupils. Responses included:

> I was about to lose faith in professional development, the overload in a short period of time … this [present model] is more practical, not too much information … you go away with an idea that you can work on with children in your school.

All of the participants stressed the importance of professional development providing opportunities for teachers to collaborate with each other, share ideas and participate in pedagogical discussions. The following remark typifies this view: 'collaboration is extremely important; because of the isolation of working in small schools … meeting people who are like-minded … science is the thing that pulls us together'. There was a general consensus among participants that unlike other forms of professional development they had experienced, WSSP provided opportunities for collaboration. Comments included: 'support, camaraderie, and a focus on science … you bring back other people's ideas to your own school' and 'we have open discussions about teaching and learning at the workshops'. One of the most experienced teachers talked about the importance of professional development in the breakdown of teacher isolation. According to him, with the previous professional development courses he attended, 'you just received information from the course facilitator and you then went back to the privacy and isolation of your own classroom'. Furthermore, he stressed:

> an important aspect of professional development should be getting to know new colleagues, we can be very isolated out in small country schools … walking into other people's schools [workshops took place in schools] helps you to get good ideas for your own school.

All of the teachers commented on the importance of making professional development relevant to their needs. The following comment is representative of what participants said: 'I have attended a number of in-service courses where someone else [facilitator] just throws things [information] at you, you don't get a say in it, here [workshops] we get a say in the material we cover'. Three teachers across the three cluster groups suggested that one of the strengths of the present programme was that it gave them a sense of ownership of the professional development. Comments included: 'this project was very relevant to our needs, we could choose the topics [science] on the programme, it was what we wanted to do … you never felt under pressure' and 'it was great that you came out to our school at the start and asked us about our views of teaching and learning of science … and asking us what we would like to do at the workshops'.

Discussion

The revised primary science curriculum (Department of Education and Science 1999) has been formally implemented in Irish primary schools since 2003. Findings from this study have shown that, after teaching pupils primary science for

nine years, a lack of confidence, science knowledge and expertise in the teaching of this subject has impacted negatively on the abilities of the participating teachers to teach science effectively. There is no reason to believe that the participants in the current study were untypical of Irish primary teachers more widely. It has also demonstrated that a targeted participatory model of professional development can bring about positive changes in teachers' confidence and competence in the teaching of science, in teachers' attitudes to teaching science and not least in teachers' classroom practice.

The findings of the study clearly show that prior to their participation in the programme the majority of teachers had low confidence in their ability to teach primary science effectively to their pupils. In fact, many of them did not understand a number of the science concepts essential to the teaching of primary science. These are similar to the international concerns mentioned earlier. Harlen and Holroyd (1997) argue that teachers with low confidence and understanding are likely to have a poor self-image as a teacher of science and teach as little of the subject as they can get away with. Post-intervention results reveal that teachers' involvement in the programme helped them to extend their knowledge of science on a number of fronts and to increase their confidence in teaching primary science. Such gains in teachers' understanding of science concepts are a fundamental part of improving the quality of teaching and learning in science (Harlen 1997).

The responses to interview questions clearly indicated that the approach taken by WSSP led to inspiring changes and advances in the teaching of science in the classrooms of the participants. The teachers spoke enthusiastically about their eagerness to do more hands-on activities and carry out innovative teaching methodologies with their pupils. Most importantly, teachers emphasised the positive impact of the workshops on their pedagogical attitudes, capabilities and practices, and on the quality of their pupils' learning experiences. The participants commented on the inadequate professional development they received prior to their involvement in the WSSP programme. The characteristics of effective professional development identified by the teachers were, in general, the same ones identified in the research literature (Hawley and Valli 1999, Garet *et al*. 2001, Guskey 2003, Hogan *et al*. 2007) as significant factors of effective professional development design. The teachers wanted professional development courses that were ongoing, relevant to their needs and collaborative in nature.

The author attributes the positive findings reported in this study to the careful design and implementation of the professional development programme. The WSSP pulled together features identified as fundamental for successful professional development and good teaching (Desimone 2009). An important finding of the programme showed that it took some time for teachers to learn new content, change their classroom practice and develop positive attitudes towards school science. The long duration was a strength of the programme. It allowed teachers the opportunity to: establish trust and meaningful collaboration with other teachers, as well as with the researcher; and try out activities picked up in workshops with their pupils back in the classrooms. This finding reinforces the point that professional development planners and providers need to consider professional development as a long-term process of change, rather than isolated events.

The programme dealt with the content that pupils are expected to learn and problems teachers might face when teaching the content. Professional development programmes that are concerned with teachers' knowledge of specific subject matter

and their awareness of how children learn that subject matter are very effective at bringing about real change in teachers' knowledge, attitudes and classroom practice (Kennedy 1998, Garet *et al*. 2001). To make the programme as meaningful as possible for the participants (Guskey 2003), the workshop content varied from one workshop to the next in response to teachers' needs.

The findings also show that the programme helped the participating teachers to develop a deeper understanding of the particulars of the science curriculum. This was achieved by engaging the participants in learning science through inquiry, tailored to each individual's content knowledge of science. As teachers' understanding of science content and pedagogy increased, they became more comfortable and confident teaching science and were more prepared to use a variety of innovative teaching methodologies in their classrooms; bringing about productive changes in classroom practice.

The WSSP provided teachers with the opportunities to engage in a range of hands-on activities that their pupils would subsequently experience. This made it easier to transfer new ideas to their classroom context. Such an approach to professional development provided the teachers with opportunities to shape and pace activities and discussions to suit their individual needs and not to be tied to the 'outsider's' imposed agenda and timeframe.

The programme was highly collaborative in nature: teachers were encouraged to work in groups, share ideas and resources and engage in pedagogical discussions. Once they built up a trust and rapport among themselves and with the facilitator, the majority of participants spoke openly and frankly about their successes and difficulties in teaching science. All too often after attending a 'traditional' form of professional development teachers are left on their own to implement what they have learnt back in their classroom. This programme was structured to provide participants with regular follow-up, feedback and support. This support definitely had a positive influence on teachers' confidence in teaching science. Planners of professional development programmes need to know that for a development programme to be effective it should provide participants with the opportunity to implement new ideas in their classroom practice. Feedback on teachers' efforts to change their classroom practice needs to be provided, if that change is to be sustained (Guskey 2002). The WSSP did not just demonstrate new techniques and deepen teachers' science knowledge, it asked teachers to explain and defend what they currently think and do in their classroom practice. Thus, teachers became more interested in their pupils' thinking and how they learn. This was influential in leading to a change of teaching practice for many of the participants.

Independently, the characteristics outlined above are not new. However, this study has shown that linking them together in a framework increases the potential of developing effective long-term professional development for teachers.

Implications for professional development

Findings from the present study have important implications for the professional development of teachers both nationally and internationally. The WSSP model represents a form of professional development springing from a different conceptual basis and with a more discerning practical orientation than the 'traditional' form generally experienced by primary teachers in the Irish context. In terms of Kennedy's (2005) analytical framework of professional development, the WSSP model can be seen as 'transformative'; that is, it has the capacity to support

considerable professional autonomy and bring about teacher change and development. On the other hand, the 'traditional' model of professional development as experienced by primary teachers tends to be 'transmissive' in nature, it has the transmission of knowledge as its main aim and has the least capacity to support professional autonomy or bring about teacher change (Kennedy 2005, p. 246).

Changing teachers' classroom practice is a complicated and difficult process and traditional delivery models are ineffective at bringing about change in classroom practice (Guskey 2003, Darling-Hammond *et al*. 2009). The results of this study suggest that a professional development model that emphasises continuity, active participation and relevant content and gives teachers opportunities to reflect on the application of their learning can promote positive changes in teaching science and classroom practice. The findings support Desimone's (2009, p. 183) 'core conceptual framework' of how teachers' participation in effective professional development can positively impact on their classroom practice by enhancing their confidence, content knowledge, skills and confidence in teaching science. 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.

The isolation of teachers from their professional colleagues has been one of the more enduring features in Irish schools (OECD 2005). This is especially true for teachers in small rural schools. According to O'Sullivan *et al*: 'there is little evidence of any deprivatisation of practice or feedback given to practising teachers other than those at induction stage into the practice' (2011, p. 8). The WSSP has made considerable inroads in breaking down that professional isolation and contributed to developing a learning community; that is, the coming together of teachers in a group to develop shared meaning and identify shared purposes to improve pupil learning (Hord 2009). Key to this was the development of a culture of meaningful collaboration. This involved a number of strategies, including building-up of trust over time and encouraging teachers to critically review their own classroom practice and believe in the relevance and importance of what they are engaged in.

Currently in Ireland professional development is mainly directed towards achieving the needs of the system. The content tends to reflect policy initiatives deemed as valuable by governments of the day: 'It is about building teacher skills, rather than capacity. The focus is curricular change rather than developing the person of the teacher' (O'Sullivan *et al*. 2011, p. 8). As a result little value is placed on teachers' needs and their sense of ownership is reduced. Ireland is not immune to the economic and political effects of the pressures of neoliberalism. However, they are not as pronounced as they are in other countries such as England (Furlong 2013). Furlong stresses that, unlike in England, teacher trade unions in Ireland have a robust influence on educational policy and the General Teaching Council is strong. However, over the last decade or so, accountability logistics have begun to impact upon educational policy in Ireland. This takes the form of teacher learning designed to bring about improved student outcomes on standardised tests in the areas of literacy and numeracy (e.g. Trends in International Mathematics and Science Study and Programme for International Student Assessment). The most recent PISA (OECD 2010) results saw Ireland's ranking in reading fall from its 2006 fifth ranking to 17th. Sugrue (2011) argues that this, 'has provided the context for a new national plan

focused on improvement of literacy and numeracy, accompanied by planned intensification of national testing consistent with emphases elsewhere' (2011, p. 796). Fraser *et al*. (2007, p. 166) argue that 'models of education that rely on notions of business efficiency are limited in scope'.

A shift in professional culture is needed to bring about a more balanced approach between professional development that supports needs of the system and that of the individual. Shifting professional culture is a complex and long-term process. However, a number of research and development projects have already begun to lay the foundations for 'effective' alternative models of professional development. Examples of these include, the Teaching and Learning for the 21st Century Project (Hogan *et al*. 2007) and the Fibonacci Project (2011–present). Both projects seek to build the capacity of teachers to become authors of their own work and to assist pupils in taking responsibility for their own learning. The Teaching Council of Ireland has, as part of its remit, the development of policy and practice of teacher professional development. In its Policy on the Continuum of Teacher Education, for the first time there is an indication that CPD needs to cater for the needs of the teacher:

> Effective CPD, which is participative in nature, should encourage teachers to evaluate their pedagogical beliefs and practices, to critically reflect on their professional practice and working environments and to engage in professional collaboration. (Teaching Council of Ireland 2011, p. 20)

Policy-makers and providers need to consider the growing international evidence of how an emphasis on a wider concept of education involving 'robust, collaborative inquiry amongst teachers into their work, not only results in much more sustained student learning, but also leads to improved outcomes on more standardised measures of student assessment' (Hardy and Rönnerman 2011, p. 464).

In knowledge economies, governments cannot afford to ignore the importance of providing vibrant learning environments from childhood onwards. In particular, they cannot afford to neglect emergent ideas that cultivate teachers' innovative capacities to build and sustain such environments. Regrettably, at a time of major economic recession and educational cutbacks, this may not become a high priority.

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