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Professional learning in primary science: developing teacher confidence to improve the leadership of teaching and learning

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ABSTRACT

The worrying decline in the status of primary school science in schools in England has been linked to low teacher confidence in teaching science and to schools being heavily focused on achievement in English and mathematics. This article reports on a novel professional learning strategy that was provided for 23 primary science leaders over five half-day workshops. Workshops focused on key topics that teachers reported having least confidence in teaching. Through a structured series of learning episodes, each workshop included knowledge and skills acquisition, opportunities to apply new knowledge and skills to primary-focused practicals, the introduction and application of scientific vocabulary, discussion and reflection time. Findings from pre- and post-workshop questionnaires undertaken with all participants and in-depth interviews with eight participants were examined from a phenomenological perspective. Participants reported that the workshops had significant and positive influences on raising their ability to teach science effectively and to build their confidence in leading colleagues. Participants also reported that the status of science in their schools had been improved.

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Introduction

Studies over the past two decades have indicated a concerning decline in the status of science in primary schools in England, despite it being, along with English and mathematics, one of the three core subjects in the National Curriculum (Bianchi et al., 2021; Harlen & Holroyd, 1997; Leonardi et al., 2017; Murphy et al., 2007; Ofsted, 2019; Pell & Jarvis, 2001; Wellcome Trust, 2020). However, primary science in England has probably never been especially well taught. Jarvis and Pell (2004) found that primary teachers lacked the necessary deep understanding of science concepts, and this influenced their ability to teach science well. Some 17 years later, Bianchi and colleagues similarly found that primary teachers lacked science subject knowledge

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relevant to their year group; as a consequence, children's preconceptions were inadequately challenged and children's curiosity and questioning of phenomena was not encouraged (Bianchi et al., 2021, p. 6). This finding is supported by Ofsted (2019) who report that 'teachers' subject knowledge and their depth of planning was not strong enough to sequence the knowledge and skills that pupils needed to learn' (p. 5) and that they had 'a limited knowledge of progression' (p. 6).

Ofsted's latest review of science reports that primary science is on average only taught for 1 h and 24 min each week and that only 31% of senior leaders see science as important (Ofsted, 2021). Primary teachers have, for many years, voiced their lack of confidence to teach science and their feelings of being ill-equipped to respond to children's questions or to resolve issues where investigations fail to work (Ofsted, 2021). As a consequence, many primary teachers avoid child-led and child-designed science investigations. The amount of science taught each week by primary teachers is related to their science qualifications and their years of service, with an increase in each of these being correlated with greater provision of science (Leonardi et al., 2017). This suggests that primary teachers with a deeper understanding of science and teachers with more confidence about teaching science spend more time teaching science to their pupils.

Recommendations made to support primary science pedagogy in England over the last two decades (Bianchi et al., 2021; Ofsted, 2013, 2019; Wellcome Trust, 2014) appear to have been largely overlooked and have certainly not led to increases in funding. The Confederation of British Industry (CBI) has argued for a greater emphasis to be placed upon primary science, highlighting the importance that primary science educators have in engaging young people in science so that more young people seriously consider science and science-related careers (CBI, 2015), and studies have suggested that aspects of a child's attitude towards science and indeed their 'science identity' are being formed at a very early age and that this influences later career choices (Archer et al., 2013; DeWitt et al., 2014; Huang et al., 2019).

Much of the evidence describing a decline in the quality of science provision in primary schools in England suggests a strong link to the changing attitudes of head teachers, where the dominance of mathematics and English (sometimes now referred to as numeracy and literacy) over other subjects has resulted in a fall in the status of science (Leonardi et al., 2017; Ofsted, 2019; Wellcome Trust, 2014). The situation has been exacerbated by the lack of investment in resources to teach practical science (Leonardi et al., 2017; SCORE, 2013). Somewhat naively (or disingenuously), Ofsted (2013) had suggested that the decline in status of science is a result of 'weak leadership', rather than a consequence of imposed government accountability measures for improving numeracy and literacy. More positively, in a more recent publication, Ofsted (2019, p. 5) state that 'School leaders need to ensure that teachers have deep subject knowledge', which acknowledges the importance of teacher subject knowledge and its influence on the quality of teaching and learning in science.

The importance of leadership

Primary teachers in state schools in England are typically expected to teach the full range of subjects prescribed by the National Curriculum (DfE, 2013). This places great emphasis on teachers having a broad and deep understanding of some ten subjects. Leadership of subject areas in English primary schools tends to be shared across the school's teaching staff. The primary science leader's role is one of ensuring that colleagues are supported in teaching science and that the school has a science curriculum that complies with the National Curriculum for science in terms of its content and progression. A science lead(er) may be asked to monitor and evaluate science performance across the school and use this information to suggest what professional learning is required for colleagues. However, science leads rarely line manage colleagues in the usual way that line management is understood (Earle & Bianchi, 2022).

The influence that a science lead has on colleagues' confidence to engage with science positively should not be underestimated. Buchanan et al. (2020) argue that science leader professional learning is a critical aspect of the ongoing, non-linear, and iterative processes of change, where new pedagogies are explored with colleagues. Sharing ideas with others in a non-threatening, supportive and collaborative manner can help schools develop their shared vision and principles for science (Lochmiller & Cunningham, 2019; Poekert et al., 2020). This is consistent with English and Ehrich (2017) who consider leadership to be co-experienced, interactive, dialogic and intersubjective. Ofsted (2021, p. 25) state that 'A high-quality science education depends on effective subject and school leadership', that this begins with 'sufficient curriculum time' and that those teaching science need to 'have access to regular, high-quality subject-specific continuous professional development (CPD)'.

This article reports on a sequence of five professional learning (PL) workshops that, based on the significant evidence from the literature, were designed to build science leaders' knowledge and understanding of science and so improve their confidence to teach science, and to more confidently lead science in their schools. Science leaders were encouraged to share their pedagogical approaches and leadership strategies that they felt enhanced pupils' learning through critical dialogue with each other in each session (Parker et al., 2016). A focus was placed on 23 science leaders from English primary schools located in London.

Materials and methods

The study was driven by the following research question: *In what ways did a series of bespoke professional learning workshops influence primary teachers' perceptions of their confidence to teach science and how did this impact their leadership of others?* In this paper, the principal aim, having answered the research question, is to present design principles for effective science PL workshops. Investigating the impact of the PL on teachers' instructional confidence helps establish the validity of the approach.

What is professional learning?

Professional learning (PL), often referred to as 'professional development' or more commonly as 'continued professional development' (CPD), can range from a purely performative experience, being heavily influenced by external accountability towards imposed reforms, to a more transformative experience, which tends to be more personalised and driven by collaboration and with a student-centred focus (Kennedy, 2015; King, 2019). Whichever term is used, there tends to be agreement that effective PL should increase teacher expertise, leading to improved practice and ultimately enhanced student learning and engagement (Earley & Porritt, 2010; King, 2014; Sims et al., 2021). Grice (2019) considers the purpose of pedagogical leadership to be to 'create a shared vision, a shared language, and a shared professional learning culture' (p. 359). This approach was encouraged within each workshop.

The literature identifies a number of characteristics for effective PL. Bubb and Earley (2010) maintain that PL should develop a teacher's knowledge, skills and attributes, whereas Harris and Jones (2015, p. 15) argue that effective PL must be based upon 'changing teacher practice to meet students' demands' and King (2014) states that professional development should attempt to change teachers' beliefs and attitudes. Within this study, PL will refer to the developmental processes that are intended to support teachers' understanding of science and science pedagogy, and to enable them to apply this confidently to enhance pupil learning and to improve their own leadership of science.

Structure of the workshops

To be effective, PL should engage teachers by linking ideas to key areas of their professional lives that they want to improve. It should therefore allow teachers to interact with new conceptual knowledge that relates to the practice they wish to develop. The workshops were designed to build teachers' confidence in science and to provide them with opportunities to explore a range of inquiry-based activities they could use in school with their pupils. To develop greater awareness of progression through the key stages (KS1 5–7-year-olds; KS2 7–11-year-olds), teachers were encouraged to work in groups of mixed key stages and to consider how the activities could be adapted and taught in different year groups and accommodate the range of learning needs they encountered in their school. Teachers were also asked to consider how each activity could support children's numeracy and literacy.

The PL was held across five Saturday workshops during 2016/2017, each workshop running for 4 h. The workshops each focused on one of the areas that teachers had expressed least confidence in teaching (Table 1). The aim was to ensure that teachers engaged with the same science content that their pupils would be expected to learn. To model how inquiry-led learning might be planned, activities were created that encourage active participation, collaboration, discussion about learning progression and, critically, time to reflect.

Workshops were run by the first author ('the researcher') and were designed to introduce and enable application of new knowledge to the primary context, provide opportunities for pedagogical discussions and offer ideas for practice back in schools (gap tasks). Each workshop had the same four elements, discussed below, thus offering continuity and progression. Figure 1 indicates the overall structure of the professional learning.

Developing subject knowledge and skills

Each workshop began with a 'traditional' teaching element that lasted between 30 and 40 min. To provide teachers with a deeper understanding of the science areas, each science topic was taught to GCSE[1] level (age 14–16 years) through a range of strategies, including PowerPoint information slides and researcher discourse that incorporated a range of questions to check understanding and deepen learning, enhanced by simulations (e.g.

Table 1. Science areas that teachers felt least confident in teaching and those that were chosen to form part of the PL in this project.

Topics teachers felt least confident with	Selected for PL	Useful publications
Working scientifically	Woven throughout sessions	Primary Science Assessment (2021) Association for Science Education Group (2018)
Rocks and soils	Yes	Lear (2011) Markwick (2020))
Electricity	Yes	CLEAPSS (2018) Buckley and Harvey (2014) Chapman (2014) Markwick and White (2022)
Light	Yes	Markwick (2021a) Dynamic Labs (n.d.)
Evolution and inheritance	Yes	Ford (2009) Hatcher (2015) Russell and McGuigan (2019) Markwick (2021b)
Forces	No	Time limitations precluded this from being included in the workshops
Earth and space	Yes	Markwick and Wright (2020) STEM Learning (n.d.)
Leadership	Yes	Kelly (2018) Lochmiller and Cunningham (2019) Wellcome Trust (2014)

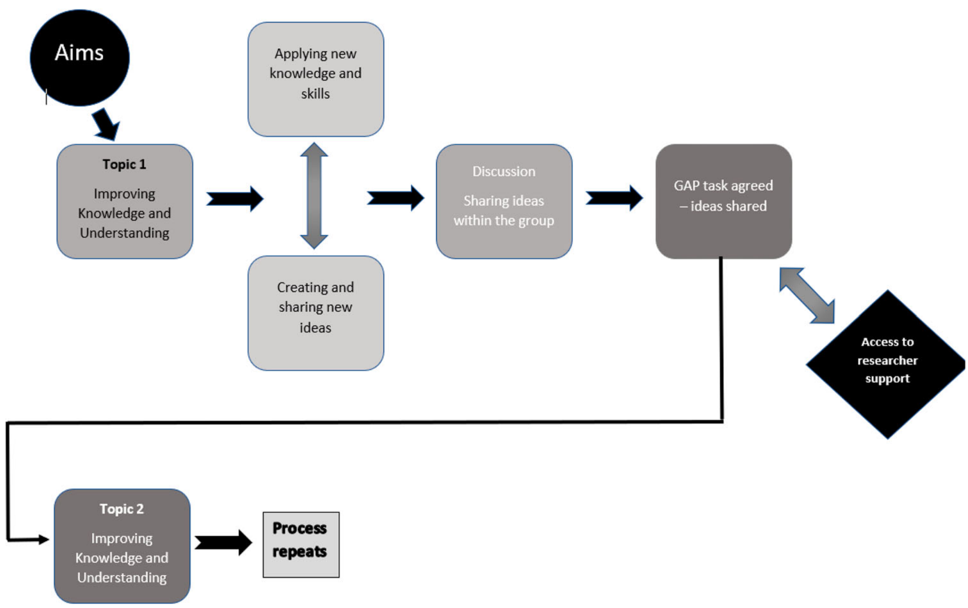

Figure 1. Professional learning structure. Topic refers to the workshop focus drawn from teacher confidence levels (Table 1).

Herrington et al., 2022; University of Colorado, 2018) and practical demonstrations. This level of knowledge acquisition was considered important for supporting teachers' confident responses to pupils' questions, that sometimes reach beyond the level they are learning (Biddulph et al., 1986). A deeper knowledge of the topics would also help teachers to identify and address children's misconceptions. Teachers were provided with summary notes on each session and many supplemented these with their own notes. A strong emphasis was placed on using scientific language in context throughout the sessions to help strengthen teachers' use of scientific vocabulary.

Applying new knowledge to inquiry-led activities focused upon primary science

Following instruction, teachers were presented with 10–15 short practical activities linked to learning within the topic being focused upon. Teachers were encouraged to work in pairs or threes and to work with colleagues from different schools, and where possible, different key stages. The activities ranged from simple experiments (requiring 5–10 min) that helped to develop conceptual understanding to more thought-provoking activities that presented a problem to be solved (requiring 15–25 min). Within this limited time frame, groups were asked to select activities that interested them the most and to complete as many activities as they could. An emphasis was placed on teachers integrating science knowledge within each practical activity and so developing a Hands-on, Minds-on approach (Millar & Abrahams, 2009). Often, activities would emphasise numeracy and literacy or ask teachers to consider how different aspects of numeracy and literacy could be embedded within the activity. Teachers were also asked to discuss how the activities might be adapted for other year groups and, in particular, for their pupils. Professional discussions were encouraged through this session. Examples of typical activities have been published in *Primary Science* (Table 1). This element lasted for 2–2.5 h.

Discussion and critical engagement

At the end of the practical activities element, teachers were invited to take part in a Q&A session where they could pose questions to be discussed by the group. This provided teachers with a forum to explore ideas about their developing pedagogy and leadership of science and it provided tangible evidence of the growing confidence teachers were developing when talking about science. Discussions were generated from teachers' curiosity about the activities and this often led to consideration about how activities might be adapted and integrated into school contexts. This element lasted for 30–45 min.

Gap tasks – teaching science in school

Gap tasks provide opportunities for teachers to apply and test new knowledge within their classroom contexts and so embed ideas into their practice (Hagevik et al., 2012); the emphasis placed on reflectivity, which was emphasised throughout the programme, has been shown to help teachers develop greater pedagogical self-awareness (McGarr & McCormack, 2014).

Following the workshop, teachers were asked to apply their new knowledge and skills back in their schools (for example, teaching science and sharing ideas with colleagues) and to be prepared to report back to the group in the following workshop. Approximately 10 min at the start of sessions (from session 2 onwards) was dedicated to feedback from teachers. Often, teachers would discuss how they had adapted the activities for their classes. Teachers were able to contact the researcher between workshops for support.

Participants

Details of the research project were shared with the science leaders at the beginning of the first PL workshop. Following our university's ethics guidance, participants were informed that taking part in the research was voluntary and that they could withdraw from the research at any time and still attend the workshops. They did not need to provide a reason for this and any data relating to them would be deleted. All teachers agreed to participate in the research project and none withdrew.

The project engaged with 23 science leaders who had varied experiences of teaching and leading science (Table 2). The design and content of the workshops developed from teachers' perceptions of their confidence in teaching science topics obtained from an initial questionnaire taken by all teachers as described below. The areas where teachers felt least confidence in teaching and those chosen to form part of the PL are listed in Table 1.

Research design and methods

A phenomenological lens was used to explore participants' perceptions of their lived professional experiences (van Manen, 2014). The process provided opportunities for teachers to reflect upon their own professional identities within the school community and so could also be considered emancipatory. Marshall and Rossman (2011, p. 91) argue, 'human actions are significantly influenced by the setting in which they occur' and so to open a window into this world, teachers' own experiences must be gathered and understood within context. The interpretivist approach taken in this research was therefore characterised by a strong desire to understand participants' perceptions of

Table 2. Demographic data for teachers in this programme.

Identifier (numbers are applied randomly)	Gender	Years of teaching	Years as science lead	Year group taught	Highest science qualification
1	F	1	≤ 1	6	Degree
2	F	1	≤ 1	3	GCSE
3	F	10	2	1	GCSE
4	F	10	1	6	GCSE
5	F	2	≤ 1	2	GCSE
6	F	10	≤ 1	1	GCSE
7	F	6	≤ 1	2	GCSE
8	F	1	≤ 1	3	GCSE
9	M	4	2	6	GCSE
10	F	10	≤ 1	6	A level
11	F	9	≤ 1	4	GCSE
12	F	10	2	1	GCSE
13	M	3	≤ 1	2	A level
14	M	7	4	4	GCSE
15	F	8	≤ 1	4	GCSE
16	F	3	≤ 1	5	GCSE
17	F	7	≤ 1	5	Degree
18	F	10	≤ 1	R	GCSE
19	F	1	2	6	GCSE
20	F	10	≤ 1	1	A level
21	M	7	≤ 1	5	GCSE
22	F	10	≤ 1	5	GCSE
23	F	5	2	4	GCSE

All teachers had at least GCSE science. Participants in bold were interviewed.

Table 3. Participant rating of workshop sessions ($n = 23$).

Workshop	% rating 9–10 (great)	% rating 7–8 (good)	% rating 1–6 (poor to satisfactory to worthwhile)
Rocks and soils	83	17	0
Electricity	83	17	0
Light	83	17	0
Evolution and inheritance	65	35	0
Earth and space	73	27	0
Average	77	23	0

their world. To be able to achieve this, a mixed-methods approach was considered the most appropriate way to optimise the quality and depth of responses obtained from participants. Both questionnaires and individual interviews were used. Both were validated by colleagues from the authors' institution, with all such feedback acted upon.

Questionnaires

Pre-workshop and post-workshop questionnaires were used in this study. The pre-workshop questionnaire was divided into two parts. The first asked participants for demographic/personal information, including age, gender, years of teaching and qualifications. This information was used in the subsequent analysis of the data gathered in the study. The second part of the questionnaire asked teachers to rate their confidence to teach science areas taken from the National Curriculum for science. This information was used to select topics to cover in the workshops (Table 1).

The post-workshop questionnaire focused upon teachers' rating of each workshop, on a scale of 1 (poor) to 10 (great) (Table 3), their perceptions of how confident they now felt teaching science (Table 4), and how they felt their leadership of science had changed following the workshops (Table 5).

All 23 participants completed pre- and post-workshop questionnaires.

Interviews

Post-workshop, semi-structured, individual telephone interviews were designed to provide participants with opportunities to explore their ideas in greater depth and for the interviewer (the first author) to probe for consistency in responses across the post-workshop questionnaire and interview. Although questions were directed, teachers were free to talk about any aspects of the PL and its influence on their professional lives. Kvale (2007, p. 2) describes such interviews as 'a construction site of knowledge', and, unsurprisingly, it was through this instrument that much of the richest data was obtained. The selection of participants for the interviews was purposeful, intended to obtain interviews that covered the range in terms of age, gender, teaching experience, and initial confidence. Eight teachers were invited to take part in the telephone interviews and all agreed. Using telephone interviews was considered to be more convenient, less invasive and impact least on teachers' lives than face-to-face interviewing. Interviews were conducted at a time most convenient for participants and on average lasted 36 min. They were audio-recorded using an MP3 device, and data were transcribed and then analysed using thematic analysis (Braun & Clarke, 2006). Rather than highlighting and using phrases and individual occurrences of words, greater meaning was gained from

Table 4. Responses from the questionnaire – post-workshop.

Question	Response: 4 (very much change)	3	2	1 (no change)	Exemplar comments
How much more knowledgeable do you feel in these topics?	6	16	1		'I can now see how science knowledge integrates with WS' (1) 'I can now see new ways to teach science and so engage children in their learning' (8) 'My knowledge of science has increased to a point where I now understand what I am supposed to teach!' (6)
How much more confident do you feel teaching these topics?	6	16	1		'Lots of good advice and ideas that have improved my understanding of science and confidence to teach it' (22) 'I have greater confidence to challenge my pupils' (23) 'I'm not worried about children's questions as much as I was' (11)
How much more have your leadership skills improved?	7	15	1		'Lots of ideas for things to do, just need time from school to do it' (13) 'I've already used some ideas in a staff INSET' (7) 'This has provided me with greater confidence to lead the subject' (10) 'I feel more confident to suggest ways to improve science and giving direction to colleagues' (11) 'I have now taken ownership of science and written a policy' (21) 'My profile has been raised in the school' (11)
Statement	**Strongly agree**	**Agree**	**Disagree**	**Strongly disagree**	**Exemplar comments**
The children I teach have made more progress in science	5	18			'Science learning is more focused now' (6) 'Children have developed their questioning skills' (7) 'Pupil progress meetings and data show outstanding progress has been made' (5) 'Children are more engaged and so achieve much more' (23)
The workshops have helped me to recognise misconceptions in science	5	17	1		'My own understanding has greatly improved, and this has helped me to recognised when pupils don't fully understand ideas' (22) 'My explanations are better and so pupils understand more and have less misconceptions' (14) 'I didn't realise that I had so many misconceptions!' (16) 'It's easier to challenge children's misconceptions' (9)
The workshops have helped me more confidently assess pupil progress in science	4	19	1		'It's difficult to assess progress when we have no levels' (13) 'The lack of guidance from the government is not helpful' (13)

(*Continued*)

Table 4. Continued.

Question	Response: 4 (very much change)	3	2	1 (no change)	Exemplar comments
My understanding of progression in science has improved	6	16	1		'I feel more confident now but it's still a work in progress' (16) 'Great ideas, just need to implement now' (14) 'More knowledge means I now know about the stepping stones across the key stages' (5) 'Knowing what children have been taught helps in planning focused learning' (6) 'Understanding how science progresses have helped us design science activities across year groups better' (11)

The table is divided into two parts to reflect the different types of responses sought (Responses range from 1 = no change to 4 = very much change). Numbers in brackets in the right-hand column identify the participant (see Table 2).

Table 5. Science leaders' levels of perceived confidence to lead science before and after the PL sessions (1 = no confidence to 10 = totally confident).

Science leader identification (see Table 2)	5	6	9	11	13	14	17	21
Confidence before PL sessions	3	4	4	2	3	4	2	3
Confidence after PL sessions	7	9	7	8	8	9	7	9
Difference in confidence	+4	+5	+3	+6	+5	+5	+5	+6

analysing whole sentences within the context of the questions that were asked. This process was used for each participant interview to ensure greater accuracy in selection of themes and later interpretations of responses.

The first author also kept field notes to record any potentially significant observations and thoughts during the PL sessions – an aide memoire of key ideas pertaining to the study that facilitated critical reflection (Maharaj, 2016; O'Reilly, 2012). These 'scratch notes' were subsequently used to complement data obtained from questionnaires and interviews and to document both the researcher's feelings and any interesting 'on-the-spot' observation made during the workshops.

Results and discussion

Questionnaires

Responses from the pre-workshop questionnaires revealed that the topics in which teachers had least confidence teaching were (numbers in brackets refer to mean responses out of 4, with 4 being most confident): Working scientifically (WS) (1.9), Electricity (2.1), Rocks and soils (2.1), Evolution and inheritance (2.2), Light (2.3) and Forces (2.8). Teachers rated their confidence in teaching other topics considerably higher (above 3). Given the limited time available for the PL sessions, the five lowest scored topics were chosen to be the foci. Working scientifically was also included within each workshop. (Table 1 provides a summary.)

Table 3 shows teachers' ratings for each workshop out of 10 (10 being the best experience). Clearly, teachers rated their experiences very highly which is consistent with the responses obtained from both questionnaires and interviews. Of course, participant satisfaction on its own is not enough. We go on to examine what teachers gained from the workshops and how this was related to the workshop design.

Knowledge, skills and developing confidence in science pedagogy and leadership

Although teachers were informed that they did not have to make any comments on the post-workshop questionnaire, most did. This suggests that many teachers wanted to voice their opinions. A selection of typical quotations from the questionnaire are presented in Table 4 to demonstrate the perceptions teachers had of the effectiveness of the workshops in terms of their own development as science teachers and leaders.

All teachers reported feeling more knowledgeable in science following the workshops with 21 of the 23 stating that they felt that their knowledge had significantly improved in all focus areas of science. Eighteen of the 23 teachers rated the improvement in their pedagogical knowledge and skills as very significant. The greatest increases in confidence to teach topics were reported in Working scientifically, Rocks and soils, Evolution and Electricity. One teacher stated that they could 'now see how science knowledge integrated with working scientifically', while others considered that their increased knowledge and improved understanding helped them to plan and teach more effective lessons. This correlated well with the teachers' perceptions of their enhanced confidence to identify and address children's misconceptions and indeed their own. One teacher felt that their improved understanding of science helped them to explain ideas in science far better and that this resulted in fewer pupil misconceptions being formed. Teachers also felt that the workshops had supported their understanding of progression in science and their ability to assess children's progress. Together this was seen as a positive step forward for the schools. However, one teacher was less confident in these areas and stated 'It's difficult to assess progress when we have no levels' and 'The lack of guidance from the government is not helpful' (Table 4). This teacher had been leading science for over 10 years and in interview explained that she had become very comfortable with the use of levels in science assessments, prior to 2009. Between 1988 and 2009 primary science was assessed using Standard Assessment Tests (SATS) in the same way as mathematics and English (Education Reform Act, 1988). The decision to stop statutory testing of science in year 6 (10–11-year-old) was made in 2009 (DfE, 2013).

In terms of confidence to lead science, all considered they had improved, with 22 of the 23 suggesting significant improvements. Comments such as 'I feel more confident to suggest ways to improve science and give direction to colleagues' were quite common and suggest that science leadership improvement came with greater confidence to understand and teach science (Table 4). Participants were also asked whether they thought their pupils had made more progress as a result of the workshops. Responses showed that 22 of the 23 participants felt that this was indeed the case.

Interviews

The semi-structured interviews enabled teachers to provide greater detail and depth when describing their PL journeys. After reading and re-reading teachers' responses four main themes were identified: Developing scientific pedagogy; Understanding progression and assessment; Impact on pupil learning; and Leadership skills and the confidence to lead others. Within this last theme, four sub-themes are discussed: Confidence, the key to improvement; Influencing the science curriculum; Organisational support; Leadership – coaching and mentoring.

Developing scientific pedagogy

Teachers were keen to speak about the improvements in their teaching as a result of their increased science knowledge and skills and increased pedagogical repertoire. Teachers freely shared their perceptions about the influence the workshops had had on their teaching and the pupils' learning. These included: 'The increase in my understanding [of science] has helped me to explain concepts more clearly to children and I now have more confidence planning experiments' (13); 'My questioning is more effective now I understand science better' (11); 'Topics are now taught with better teacher knowledge and as a result children can recall more detail' (9); and 'I have a better science knowledge and this makes my explanations better' (14). All eight interviewees commented upon children's improved engagement in lessons, for example: 'Children are now more engaged with their work and want to find out more' (17). Often this was linked to improved confidence to teach science; for example teacher 5 stated 'I really feel my confidence to teach Evolution and inheritance improved dramatically following the workshop as before I wasn't sure how to teach it because I didn't really understand it'. Another interviewee stated that 'My teaching is more creative now' and 'My children are more engaged in learning' (21). The importance of high-quality pedagogy is emphasised in a number of reviews of primary science teaching (e.g. Bennett et al., 2023; Bianchi et al., 2021).

Teachers felt positive about their confidence to plan and teach science investigations. For example, teacher 14 stated 'I've more confidence in planning investigations now', 'I am sure children are getting far more from my lessons now' and 'I now have the knowledge to confidently make lessons more enquiry-based, rather than just transmitting knowledge'. We do not claim that teachers had deeper understanding of inquiry-based teaching practices. While this may have been the case, what came through in the interviews was teachers' greater confidence with respect to teaching science investigations.

Understanding progression and assessment

Bubb and Earley (2010) found that lacking confidence to be able accurately to assess pupils' work in science caused great concern for teachers and so one interview question focused upon this issue. In the questionnaire responses, when asked if the workshops had helped to develop teachers' confidence to assess children's work in science, 22 of the 23 participants thought that their understanding of how both knowledge and skills progress in science had resulted in improved assessment of pupils' progression. Being confident to assess progress in science requires a clear understanding of the progression of knowledge and skills in the science curriculum. All the teachers thought the workshops had significantly helped them to understand progression in science, not only between year groups, but across phases. Interviewee responses included: 'I can see how the skills and knowledge progress much more clearly now' (13). Table 4 includes quotations derived from questionnaires that demonstrate how teachers' confidence to assess was supported by their understanding of knowledge and skills progression in science. Selecting activities that were considered most challenging for participants (Table 1) and the way they were linked across key stages encouraged teachers to consider how progression in learning could be envisaged. Discussions on progression were further supported by encouraging the composition of teacher groups to be cross-phase, i.e. a mix of teachers who taught younger (age 5–7) and older (age 8–11) years.

The more in-depth responses provided in the interviews supported these perceptions revealed in the questionnaires. Responses included: 'Assessing against the "big ideas" in science makes assessment more effective' (6); 'Particularly good links were made between KS1 Classification and KS2 Evolution and inheritance which I had not considered before' (14); 'I can see how the knowledge and skills build and I use this to prepare children for their next year of study' (5); 'Looking in detail at the topics has helped to clearly identify progression' (13); and 'My questioning during working scientifically is much better now and I can focus my questions to assess learning' (5); teacher 21 stated that improvements in their assessment of children's skills progression were especially significant.

Although most participants thought that their understanding of progression had improved and, as a consequence, they had more confidence to assess aspects of science, conversations during Q and A sessions demonstrated that there was confusion about exactly what to assess, how to record pupil assessments, and what to do with the assessment data. For example, 'The guidance from the government on assessment is non-existent' and 'It's difficult to assess in science with no levels or any measure to use' (13). The removal of statutory testing in science in 2009 (DfE, 2013) without providing teachers with an alternative way to measure achievement in science had caused some distress for teachers.

Impact on pupil learning

Interviews with teachers revealed that they generally felt that pupil manifested greater engagement in science following implementation of ideas from workshops and that this had enhanced learning. Most teachers said that the greater pupil engagement in science was as a result of lessons that were now better planned and taught. Responses such as 'Pupils make more progress because my teaching is more focused' (6), 'There are more investigations now and I have more ideas to improve teaching' (9), 'Exposure to a wider range of scientific enquiries and better scientific knowledge and process vocabulary has supported my children make greater progress' (11), 'Children make better progress because they are now working more scientifically and developing their language of science' (17) and 'Pupils now receive a more interesting curriculum' (21) show that participants felt strongly that their pupils had progressed well because of the participants' improvements in science pedagogy and more confident use of science vocabulary. One participant concluded that 'Pupil progress and data meetings show children are now making outstanding progress. I can also see great improvements in children's investigations' (5).

Responses obtained from both questionnaires and interviews demonstrated increased enjoyment of science by both teachers and pupils; for example: 'We all enjoy science much more' (6); 'We use great new ideas and new resources to make science more fun and have greater meaning' (11); and 'My pupils really enjoy science investigations and have begun to independently create and use data tables' (5). Responses from teachers suggest that enjoying learning about science is strongly linked to understanding what science is all about (Abrahams & Reiss, 2012). However, Ainley and Ainley (2011) found that students' interest in learning science was not always linked to their science knowledge acquisition.

A limitation of this study was that a comparison of pupil knowledge and understanding before and after the PL was not undertaken. However, the teachers' interview responses do suggest that their pupils' learning progressed following application of the new knowledge and pedagogies gained from the PL sessions.

Leadership skills and the confidence to lead others

One central aim of the study was to ascertain how participants felt that their experiences of the workshops had impacted on their leadership skills and therefore their influence on the teaching of science in their schools.

When science leaders were asked to respond on the questionnaire as to whether the workshops had helped them to develop their leadership skills, 20 of the 23 participants reported that it had made a significant or very significant impact. Interviewee comments that supported these responses included: 'it [the workshop] has provided me with more confidence to lead science' (6); 'I've learnt so much from the workshops. At the beginning I felt I was starting with a blank page, now I've written the science policy and included progression measures'; 'I know what scrutiny to do and how to do it'; 'I used ideas from the workshop to run an INSET' (21); 'it has helped me to assess children's books and teacher's marking' (9); 'it has helped me to know what to look for when observing lessons and checking books and support colleagues' (17); and 'I feel more confident in suggesting ways to improve science in my school and the federation[2]' (5). This last teacher continued to explain how their enhanced confidence had led them to apply for the role of federation science lead saying, 'I am sure that my improved confidence in science had helped to get me recognised by my school'. The teacher was successful in their application.

The science leaders' interview responses when explaining why their confidence to lead others had improved so substantially were very similar. All interviewees cited the key influences as their improved knowledge of the science curriculum and the range of teaching ideas they now felt they possessed. Responses included: 'I feel more confident to suggest ways to improve science and giving direction to colleagues' (11); and 'my colleagues have greater confidence in my suggestions now, which is possibly because I am more confident' (14).

Other reasons given as to why their confidence to lead others had improved included their new insights into how progression could be visualised and how assessment of science knowledge and skills might be made meaningful. A strong feature of how teachers perceived their leadership role was their being able to cascade information to colleagues with greater confidence. Conversations during interviews led to such responses as: 'I have a far greater range of activities that I can share with colleagues' and 'Colleagues from across our federation approach me to discuss how to plan enquiry-based activities'. Two teachers (5 and 14) noted that they had generated resources that were based upon those obtained from the project and passed these onto colleagues. One teacher (21) had provided demonstration lessons on Rocks and Soils for colleagues and commented that through informal conversations had 'explained how to teach Evolution to a colleague who had moved from year 3 to year 6'. They continued, saying 'being able to support colleagues with such great investigations makes me feel good'. Another teacher stated that they too had taught demonstration lessons saying, 'Colleagues came to watch me teach a lesson … it was really good' (14).

A new-found feeling of confidence prompted teacher 17 to comment 'I am now clear about the requirements of the science curriculum, and I know what we need to teach which I can pass onto others'. Teachers also commented on how they provided PL for colleagues. For example, teacher 6 explained how they had run several professional learning sessions for colleagues. These had included scaffolding for Working Scientifically, creating word banks for key words, updating displays, and mapping out progression in the science curriculum. These types of activities were also noted by teacher 17, who said they were now 'proud of the quality and improved prominence of science displays in the school' and of the introduction of science learning walls. Teachers also commented that introducing the new ideas learned from the workshops had already impacted upon pupil progress, saying 'children are far more engaged, and their work is better', and stated that they had implemented many of the ideas learned during the workshop to 'extremely good effect' (5). Examples included the introduction of vocabulary lists and more engaging and enquiry-led activities. What emerged from teachers' responses is that their confidence extended beyond their own classrooms, as discussed below.

Confidence, the key to improvement. It has long been held that confidence is key to successful primary science teaching (e.g. Murphy et al., 2007) and interviewees stated that their confidence levels had improved. They cited reasons such as 'I feel more authoritative because I have such a good knowledge of science now' (17); 'My profile as a science leader has significantly risen' (5); 'My confidence has grown because I have learned so much. I am sure my enthusiasm has developed for science, and this is noticeable' (21); and 'being able to confidently support others to plan science lessons that are engaging has raised my profile across the school' (11). Another participant stated 'I have developed a security in my science knowledge, with a bank of great ideas, not only about science but also about how to run PL sessions' and 'I can confidently challenge colleagues now' (21).

All science leaders spoke about how their improved confidence was a key factor in their improved ability and effectiveness to lead others. Comments included 'I know what I am talking about and so have the confidence to drive through my ideas and challenge others when I need to' (6) and 'My improved knowledge of science and of Working Scientifically has been critical in developing my leadership status' (17).

To help teachers visualise their progress, each interviewee was asked to rate their perception of the progress they had made on a 1–10 scale (Table 5). The values provided by the interviewees support the evidence gained from both the questionnaires and the non-quantitative parts of the interviews. The average score at the start of the project was 3.1 and the average score increased to 8.0 after the workshops, with all interviewees reporting a substantial improvement in their confidence to lead science in their schools. Initially, participants' confidence to lead science ranged from feelings of being very unconfident (2–3) to moderately confident (4). Following the workshops, the least confident science leaders scored themselves at 7 and three teachers scored their new confidence very highly at 9.

With improved science knowledge and access to a greater range of pedagogical approaches, science leaders' confidence to support and lead others also grew.

Influencing the science curriculum. When asked whether the experiences gained from the workshops had influenced the implementation of the science curriculum in their school, all but one teacher stated that the experiences had been significantly influential. Responses that were made included 'I have a new voice now and can influence some of the decisions about science' (6), 'The school's response to my ideas is much better now' (5) and 'I feel more secure with the curriculum and can hand on banks of ideas to colleagues' (21). Where teachers thought that the project had been less influential, this was as a consequence of having either an integrated curriculum, such as the International Primary Curriculum (IPC), in which science was often peripheral to other subjects such as mathematics, English and history, or an inflexible curriculum. For example, one teacher (21) stated that their school's rigid and limited science curriculum presented them with 'no choice in the science topics being taught'. However, here there was the intention to change the science curriculum in the following year from one dictated by the IPC themes to a stand-alone science curriculum in which all aspects of the 2014 National Curriculum (DfE, 2013) curriculum could be taught.

From the responses provided by teachers, there seems to be good evidence that the experiences provided by the workshops had influenced the way teachers perceived the science curriculum evolving in their schools. The responses provided by teachers in their interviews suggest that the iterative nature of the PL and the opportunities for teachers to share ideas and discuss contextualised challenges (Figure 1) helped to establish greater confidence in applying new knowledge and pedagogies.

Organisational support. Support structures in teachers' schools, such as approachable senior school leaders, access to a source of science expertise and adequate curriculum time for science, were also considered by some to be an important factor in ensuring effective science leadership in their school. For example, one science leader, who considered their leadership skills to have improved greatly, commented 'My head has been very supportive because they know I now have the science background to move science forward in the school' (17). Similarly, another participant stated 'It's nice to have the head behind you as it gives a bit more weight to moving things forward' (14). However, another participant who had perceived less improvement in their confidence to lead others commented on their 'frustration at not being able to make the changes they thought were important', stating 'I do feel more confident, yet to be effective I also need time to plan and implement ideas I have gained from the project' (14). This clearly implies that they felt support from their school would have been very important for any changes to take place but was inadequate.

Where less was accomplished by science leaders, notably teachers 14 and 13, it became clear that such individuals perceived their major barrier as the lack of support shown by their head teacher. One participant (14), commented that very little movement had taken place because 'no time or support from the head was given'. Teacher 13 also commented on the difficulties in taking science forward, stating that 'the head has provided me with no time and so, not surprisingly, I have had little success in writing plans or passing on information to others'. For both these teachers, there was clearly an element of frustration as although they felt far more empowered in terms of their enhanced knowledge of science and potential leadership ability, they felt equally disenfranchised by the lack of support shown by their head teacher. Teacher 13 continued by saying 'I know we need to continue to focus on literacy and numeracy, but the head must acknowledge that science too is a core subject and needs to be taken as seriously'.

The responses clearly show that for any transformation to occur in teaching and learning it must be driven or at least strongly supported by the head teacher. This aligns strongly with the findings from other studies, including Leonardi et al. (2017) and Ofsted (2019). Abrahams et al. (2014) concluded that attempts, through a continuing professional development course, to change how schools undertake practical work were more likely to be effective if undertaken with the full support of the senior management of the school.

Leadership – coaching and mentoring. When in discussion with participants, many felt strongly about the importance of their confidence if they were successfully support colleagues through offering suggested activities, explaining science concepts, and providing helpful feedback from monitoring. Being able to offer expertise in science teaching to colleagues by regularly supporting them to help them improve their science pedagogy suggests that science leaders had begun to take on the role of mentor (Howells et al., 2020). For example, teacher 9 stated 'my ability to support colleagues had undoubtedly helped to raise my status as a leader in the school' and teacher 6 stated that 'I am much better at observing lessons and giving constructive feedback. Feedback for me has become more of a professional discussion'. Other science leaders commented: 'I can now evaluate the content of children's exercise books more confidently as I know what should be in them' (17); 'can now lead on events and share my science knowledge' (2); and 'I've run a science INSET, led a work scrutiny and planned with others' (7).

Both questionnaire returns and in-depth interviews reveal a perception by participants of significant improvements in their leadership skills, which had been translated into greater confidence to mentor their colleagues. All participants referred to the workshops as being highly influential in this respect. The responses demonstrate that many science leaders had started to coach colleagues in their schools, albeit at an embryonic stage. This suggests that greater emphasis placed on coaching skills might have been a useful addition to the workshops.

Conclusions

Harlen and Holroyd (1997) argue that teachers with low self-image and confidence as science teachers are often those with a poorer understanding of science and least confidence to teach science. This supports the findings from this study which indicates that improving teachers' knowledge and skills of science and developing their repertoire of science pedagogies can have a significant influence on teacher confidence and ultimately their children's achievement.

It therefore seems likely that access to high-quality professional learning designed to address teacher needs is essential if we want to support teachers to be able to translate their science knowledge and skills into effective pedagogies that impact on children's engagement and ultimately achievement in science. This study shows that the model applied was very effective in developing teachers' knowledge and understanding of science, their pedagogical expertise and ultimately helping children to enjoy learning science more. At the same time, it is important to acknowledge that the study relies on self-reported data. It would be valuable for a future study to determine changes in teachers' classroom practices and the effects of these, if any, on student learning and engagement.

From the results from this study, it is argued that to be effective in enhancing science teaching and learning, professional learning should be designed to include the following features:

- Activities are focused upon the perceived needs of teachers and what they want to achieve for their children.
- Knowledge and skills are integrated with engaging and effective practical activities, following the 'Hands-on' and 'Minds-on' ideas proposed by Millar and Abrahams (2009), i.e. be actively engaged in linking practical to theory.
- The evolution of a scientific vocabulary is supported within a collaborative framework.
- There are opportunities for teachers to challenge and transform ideas introduced by workshops/activities.
- Time is built into the PL sequence for teachers to apply ideas back at school and to reflect upon its effectiveness with children.

We conclude that the success and ultimately effectiveness in enhancing teaching and learning culture through PL experiences must be built upon the perceptions and needs of teachers within their professional contexts.

Notes

1. GCSEs (General Certificates of Secondary Education) are the examinations customarily taken in England by 16 year-olds at the end of compulsory schooling.
2. Federation – a group of local authority (state) schools that have one governing body across all schools.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Ethics statement

The research was conducted following BERA (2018) guidelines and ethical approval was gained from the host university. Informed consent from participants was obtained for their data to be used. Participants could leave the project at any time without providing a reason and with no detriment to them or their school.

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References

Abrahams, I., & Reiss, M. J. (2012). Practical work: Its effectiveness in primary and secondary schools in England. *Journal of Research in Science Teaching*, *49*(8), 1035–1055. http://dx.doi.org/10.1002/tea.v49.8

Abrahams, I., Reiss, M. J., & Sharpe, R. (2014). The impact of the 'Getting Practical: Improving Practical Work in Science' continuing professional development programme on teachers' ideas and practice in science practical work. *Research in Science & Technological Education*, *32*(*3*), 263–280. http://dx.doi.org/10.1080/02635143.2014.931841
Ainley, M., & Ainley, J. (2011). Student engagement with science in early adolescence: The contribution of enjoyment to students' continuing interest in learning about science. *Contemporary Educational Psychology*, *36*(1), 4–12. https://doi.org/10.1016/j.cedpsych.2010.08.001
Archer, K. L., DeWitt, J., Osborne, J. F., Dillon, J. S., Wong, B., & Willis, B. (2013). *ASPIRES report: Young people's science and career aspirations, age 10–14*. King's College London.
Association for Science Education Group. (2018). *Best practice guidance*. Association for Science Education.
Bennett, J., Dunlop, L., Atkinson, L., Glasspoole-Bird, H., Lubben, F., Reiss, M. J., & Turkenburg-van Diepen, M. (2023). *A systematic review of approaches to primary science teaching*. Education Endowment Foundation.
Bianchi, L., Whittaker, C., & Poole, A. (2021). *The 10 key issues with children's learning in primary science in England*. https://www.scienceacrossthecity.co.uk/wp-content/uploads/2021/03/3634_Childrens_Learning_in_Primary_Science_Report_2020_v8.pdf
Biddulph, F., Symington, D., & Osborne, R. (1986). The place of children's questions in primary science education. *Research in Science & Technological Education*, *4*(1), 77–88. https://doi.org/10.1080/0263514860040108
Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa
British Educational Research Association [BERA]. (2018). *Ethical guidelines for educational research* (4th ed.). British Educational Research Association.
Bubb, S., & Earley, P. (2010). *Helping staff develop in schools*. Sage.
Buchanan, R., Mills, T., & Mooney, E. (2020). Working across time and space: Developing a framework for teacher leadership throughout a teaching career. *Professional Development in Education*, *46*(4), 580–592. https://doi.org/10.1080/19415257.2020.1787204
Buckley, A., & Harvey, K. (2014). Squishy circuits: A novel way to teach electricity with playdough! *Primary Science*, *135*, 12–14.
CBI. (2015). *Tomorrow's world – Inspiring primary scientists*. http://www.cbi.org.uk/tomorrowsworld/assets/download.pdf
Chapman, S. (2014). Teaching the 'big ideas' of electricity. *Primary Science*, *135*, 5–8.
CLEAPSS. (2018). Fun activities: The electric issue. *Explore*, *4*, 1–8.
DeWitt, J., Archer, L., & Osborne, J. (2014). Science-related aspirations across the primary-secondary divide: Evidence from two surveys in England. *International Journal of Science Education*, *36*(10), 1609–1629. https://doi.org/10.1080/09500693.2013.871659
DfE. (2013). *The national curriculum*. HMSO.
Dynamic Labs. (n.d.). *Home*. https://primaryschoolscience.co.uk/index.html
Earle, S., & Bianchi, L. (2022). What role can professional learning frameworks play in developing teacher agency in subject leadership in primary science? *Professional Development in Education*, *48*(3), 462–475. https://doi.org/10.1080/19415257.2021.1942142
Earley, P., & Porritt, V. (2010). *Effective practices in continuing professional development*. Institute of Education, University of London.
Education Reform Act. (1988). *HMSO*. Retrieved March 1, 2022, from https://www.legislation.gov.uk/ukpga/1988/40/pdfs/ukpga_19880040_en.pdf
English, F., & Ehrich, L. C. (2017). Disambiguating leadership: The continuing quest for the philosopher's stone. In G. Lakomski, S. Eacott, & C. Evers (Eds.), *Questioning leadership: New directions for educational organisations* (pp. 3–16). Routledge.
Ford, A. K. (2009). Rocks, fossils and evolution. *Primary Science*, *107*, 31–34.
Grice, C. (2019). Leading pedagogical reform. *International Journal of Leadership in Education*, *22*(3), 355–370. https://doi.org/10.1080/13603124.2018.1463462

Hagevik, R., Aydeniz, M., & Rowell, C. (2012). Using action research in middle level teacher education to evaluate and deepen reflective practice. *Teaching and Teacher Education*, *28*(5), 675–684. https://doi.org/10.1016/j.tate.2012.02.006

Harlen, W., & Holroyd, C. (1997). Primary teachers' understanding of concepts of science: Impact on confidence and teaching. *International Journal of Science Education*, *19*(1), 93–105. https://doi.org/10.1080/0950069970190107

Harris, A., & Jones, M. (2015). Professional learning as community. *Professional Development Today*, *17*, 18–22.

Hatcher, C. (2015). Effective strategies for teaching evolution: The primary evolution project. *Primary Science*, *135*, 25–26.

Herrington, D. G., Hilborn, S. M., Sielaff, E. N., & Sweeder, R. D. (2022). ChemSims: Using simulations and screencasts to help students develop particle-level understanding of equilibrium in an online environment before and during COVID. *Chemistry Education Research and Practice*, *23*(3), 644–661. https://doi.org/10.1039/D2RP00063F

Howells, K., Lawrence, J., & Roden, J. (Eds.). (2020). *Mentoring teachers in the primary school: A practical guide*. Routledge.

Huang, L., Huang, F., Oon, P. T., & Chi Kuan Mak, M. (2019). Constructs evaluation of student attitudes towards science. *EURASIA Journal of Mathematics, Science and Technology Education*, *15*(12), em1792. https://doi.org/10.29333/ejmste/109168

Jarvis, T., & Pell, A. (2004). Primary teachers' changing attitudes and cognition during a two-year science in-service programme and their effect on pupils. *International Journal of Science Education*, *26*(14), 1787–1811. https://doi.org/10.1080/0950069042000243763

Kelly, L. (2018). The ASE primary science leaders' survival guide. *ASE*. https://www.ase.org.uk/resources/ase-primary-science-leaders-survival-guide

Kennedy, A. (2015). 'Useful' professional learning … useful for whom? *Professional Development in Education*, *41*(1), 1–4. https://doi.org/10.1080/19415257.2014.983787

King, F. (2014). Evaluating the impact of teacher professional development: An evidence-based framework. *Professional Development in Education*, *40*(1), 89–111. https://doi.org/10.1080/19415257.2013.823099

King, F. (2019). Professional learning: Empowering teachers? *Professional Development in Education*, *45*(2), 169–172. https://doi.org/10.1080/19415257.2019.1580849

Kvale, S. (2007). *Doing interviews*. Sage.

Lear, J. (2011). *Rocks and soils*. https://www.teachprimary.com/learning_resources/view/cross-curricular-ks2-topic-rocks-and-soils

Leonardi, S., Lamb, H., Howe, P., & Choudhoury, A. (2017). 'State of the Nation' report of UK primary science education. *Wellcome Trust*. https://wellcome.org/reports/state-nation-report-uk-primary-science-education

Lochmiller, C. R., & Cunningham, K. M. W. (2019). Leading learning in content areas: A systematic review of leadership practices used in mathematics and science instruction. *International Journal of Educational Management*, *33*, 1219–1234.

Maharaj, N. (2016). Using field notes to facilitate critical reflection. *Reflective Practice*, *17*(2), 114–124. https://doi.org/10.1080/14623943.2015.1134472

Markwick, A. (2020). Science Swap Shop, *Primary Science*, *163*, 17–20.

Markwick, A. (2021a). Working Scientifically with Shadows. *Primary Science*, *165*, 28–30.

Markwick, A. (2021b). Teaching adaptation: Some tried and tested activities. *Primary Science*, *168*, 29–32.

Markwick, A. and White, A. (2022). Working scientifically with fruit and vegetable batteries. *Primary Science*, *171*, 11–14.

Markwick, A. and Wright, M. (2020). Meteorite Impact! Applying maths and English to a science investigation. *Primary Science*, *163*, 25–28.

Marshall, C., & Rossman, G. B. (2011). *Designing qualitative research* (5th ed.). Sage.

McGarr, O., & McCormack, O. (2014). Reflecting to conform? Exploring Irish student teachers' discourses in reflective practice. *The Journal of Educational Research*, *107*(4), 267–280. https://doi.org/10.1080/00220671.2013.807489

Millar, R., & Abrahams, I. (2009). Practical work: Making it more effective. *School Science Review*, *91*, 59–64.
Murphy, C., Neil, P., & Beggs, J. (2007). Primary science teacher confidence revisited: Ten years on. *Educational Research*, *49*(4), 415–430. https://doi.org/10.1080/00131880701717289
Ofsted. (2013). *Maintaining curiosity in science: A survey into science education in schools*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/379164/Maintaining_20curiosity_20a_20survey_20into_20science_20education_20in_20schools.pdf
Ofsted. (2019). *Intention and substance: Further findings on primary science from phase 3 of Ofsted's curriculum research*. https://www.gov.uk/government/publications/intention-and-substance-primary-school-science-curriculum-research
Ofsted. (2021). *Research review series: Science*. https://www.gov.uk/government/publications/research-review-series-science/research-review-series-science
O'Reilly, K. (2012). Ethnographic returning, qualitative longitudinal research and the reflexive analysis of social practice. *The Sociological Review*, *60*(3), 518–536. https://doi.org/10.1111/j.1467-954X.2012.02097.x
Parker, M., Patton, K., & O'Sullivan, M. (2016). Signature pedagogies in support of teachers' professional learning. *Irish Educational Studies*, *35*(2), 137–153. https://doi.org/10.1080/03323315.2016.1141700
Pell, T., & Jarvis, T. (2001). Developing attitude to science scales for use with children of ages from five to eleven years. *International Journal of Science Education*, *23*(8), 847–862. https://doi.org/10.1080/09500690010016111
Poekert, P. E., Swaffield, S., Demir, E. K., & Wright, S. A. (2020). Leadership for professional learning towards educational equity: A systematic literature review. *Professional Development in Education*, *46*(4), 541–562. https://doi.org/10.1080/19415257.2020.1787209
Primary Science Assessment. (2021). *Home*. https://www.planassessment.com/
Russell, T., & McGuigan, L. (2019). Teaching and learning about evolution: A developmental overview. *Primary Science*, *107*, 33–35.
SCORE. (2013). *Resourcing practical science in primary schools*. SCORE.
Sims, S., Fletcher-Wood, H., O'Mara-Eves, A., Cottingham, S., Stansfield, C., Van Herwegen, J., & Anders, J. (2021). *What are the characteristics of effective teacher professional development? A systematic review and meta-analysis*. https://files.eric.ed.gov/fulltext/ED615914.pdf
STEM Learning. (n.d.). *Year 5: Earth and space*. https://www.stem.org.uk/resources/community/collection/12347/year-5-earth-and-space
University of Colorado. (2018). *PhET simulations*. Retrieved March 20, 2022, from https://phet.colorado.edu/
van Manen, M. (2014). *Phenomenology of practice*. Routledge.
Wellcome Trust. (2014). *Great science primary leadership at primary school*. https://wellcome.org/sites/default/files/great-science-subject-leadership-wellcome.pdf
Wellcome Trust. (2020). *Evaluation of the primary science campaign*. https://wellcome.org/sites/default/files/evaluation-of-the-primary-science-campaign-2020.pdf