Enquiry-based science in the infant classroom: ‘letting go’

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Acknowledgements: This research was supported by the [European Union Seventh Framework Programme FP7/ 2007 – 2013] under grant agreement [266647].

Abstract

Enquiry-based science in primary classrooms is key to encouraging children’s interest and curiosity about the world around them and as a result helps to stimulate their understanding and enjoyment of science. Yet many primary teachers lack the confidence to implement enquiry-based approaches effectively. The reasons are myriad and often result in the teacher controlling and orchestrating the lesson leaving little room for children’s exploration and autonomy. This paper explores how one infant school teacher was willing to relinquish control and ‘let go’ expanding her pedagogical repertoire to manage the many obstacles to including enquiry-based science in her classroom. The autonomy the children were given resulted in genuine enquiry-based science with the consequential benefit to their learning. Furthermore the teacher’s confidence and self-efficacy seem to have been raised ensuring that that she would continue to include enquiry-based science as part of her practice in the future. Whist this is a small scale study and therefore lacks generalisability used as a model for other primary teachers this approach could help them overcome their reticence to engage with enquiry-based science.

Key words

enquiry-based primary science; teacher confidence; student autonomy; engagement, curiosity

Introduction

The experiences in science at primary level that young children have can sow the seeds of interest and understanding in science. This view is particularly apposite when enquiry-based approaches are considered, as they have been shown to be efficacious in stimulating children’s curiosity and interest about the world (Bartley, Mayhew, and Finkelstein 2009; Bell, Urhahne, Schanze, and Ploetzner 2010; Engel and Randall 2008). Indeed, some of the key goals for early years education worldwide are to gain an understanding of the world through observation and exploration (DfE 2014a; DfE 2014b; National Research Council 2000; Poisson 2000). Therefore, capitalising on the benefits of enquiry-based approaches for young children to learn science not only enables practitioners to address these goals, but may also facilitate a long-term interest in science by stimulating children's innate tendency to want to learn and know more, to feed them when they are still in their 'curiosity golden age' (Rocard 2007). However, the way in which science, including primary science is often taught leaves little room for enquiry-based learning and the development of scientific literacy (Appleton and Kindt 1999; Harlen and Holroyd 1997: Osborne and Dillon 2008).

In a desire to reverse this trend in primary classrooms across Europe, Pri-Sci-Net, an EU funded FP7 project, aimed to promote the use of an enquiry-based learning approach among teachers teaching science to young children between 3-11 years. The Pri-Sci-Net team of about 30 primary science educators from 15 EU Member States worked together to develop a common vision for enquiry-based learning in science and formed the basis for a teaching and learning framework with implications for learning science, learning to do science, and learning about science. The framework considers that children will:

1. engage actively in the learning process with emphasis on observations and experiences as sources of evidence;
2. tackle authentic and problem-based learning activities where the correctness of an answer is evaluated only with respect to the available evidence and getting to a correct answer may not be the main priority;
3. practice and develop the skills of systematic observation, questioning, planning and recording to obtain evidence;
4. participate in collaborative group work, interact in a social context, construct discursive argumentation and communicate with others as the main process of learning;
5. develop autonomy and self-regulation through experience.

Following this framework, it is expected that the children will have autonomy over their own learning by being actively engaged in investigations and involved in working out meanings and explanations in groups through the social construction of knowledge (Gatt and Vella 2003). As a result, they will be engaged physically, mentally and socially to different degrees, but with the result that they understand not only scientific knowledge, but also what it means to do science.

Using a constructivist approach, the teacher's role is to act as a guide to learning by providing a role model of an inquiring learner rather than as the sole bearer of expert knowledge. Instead, the teacher facilitates the negotiation of ideas as the students reconstruct their knowledge by interacting with objects in the environment and engage in higher-level thinking and enquiry-based problem solving (Crawford 2000).

In England infant classrooms are flexible learning spaces that provide children with opportunities to engage with learning stimuli either alone or in groups and also provide time for them to come together for instruction and discussion to reflect on, and share their learning. This environment would seem to be ideally suited to foster enquiry-based science and yet as noted above genuine enquiry-based learning in primary science (as further defined and outlined below) is rare and the reasons, discussed below, are manifold. Enquiry has long been recommended as a basis for student learning, especially in science and mathematics, and this can be capitalised upon because young children naturally ask questions and explore in order to understand the world (Wang 2009). Ellis and Kleinberg (1997) posit that young children have a fundamental right to have their many enquiries and questions treated with respect, and their curiosity invested in emotionally and intellectually by adults. Furthermore, their natural tendency to narrate their experiences needs to be taken as a starting point and built on in (science) education. Therefore, Ellis and Kleinberg propose that experiences need to be provided and the processes, explanations and interpretations of science content are construed within an overall framework of the child's developing competence so that "… the child is to be helped to become conscious of what they are doing and how their knowledge relates to adult conventions". Piaget noted that children from 18 months to 7 years (the pre-operational stage) develop the capacity to apply if/and/then reasoning to an imaginary representation, in which language acquisition plays an important role as it is used to name objects, events and situations (Lawson 2003; Piaget 1954). At 18 months, a child can typically already "wonder 'what if', contemplate 'as if', and deduce 'what must have been'" even without perceptual evidence (Meltzoff 1990, 22). Young children therefore have the capacity to take part in enquiry-based learning activities, as they are capable of the necessary reasoning. Even though infants need more time and teacher guidance than older children, we argue that they can and should be allowed to perform scientific enquiries. Commensurate with their cognitive capabilities and their innate inquisitiveness and curiosity, they should be given extensive opportunities to perform observations, accompanied by simple measurements (e.g. drawings of changes, non-standard measures or completing simple worksheets and graphs), and to talk in groups about their ideas, observations, and explanations. We argue and demonstrate in this paper that under the close guidance of a confident teacher this is possible and can result in very positive outcomes. M However, as Ellis and Kleinberg (60) note, "enquiry needs to [be part of] the teacher's repertoire if children are to see it as valuable, learn to do it, and learn through it". The research presented here adds to the literature by addressing the issues of how enquiry-based approaches to teaching and learning science in infant classrooms might be facilitated.

Therefore, the aim of this paper is to explore how enquiry-based science, as defined above, can be facilitated in the infant classroom. It will also consider what, if any benefits, are accrued for teachers and learners, by examining the practice of one infant school teacher who was part of the Pri-Sci-Net project.

Background literature

A major obstacle to adopting an enquiry-based approach to teaching science that has been of concern for decades is the number of primary school teachers who lack the confidence to teach science because they do not have a scientific background (e.g. Abd-El-Khalick and Akerson 2004; Appleton and Kindt 2002; Hanson and Akerson 2006; Jarrett 1999; Lloyd et al. 1998; Murphy, Neil and Beggs 2007; Stevens and Wenne, 1996; Trundle, Atwood and Christopher 2002; van Zee, Lay and Roberts 2003). Nevertheless, most of these teachers will have had some formal science education at school, but this has often left them with negative attitudes towards science and science teaching (Parker and Spink, 1997; Mulholland and Wallace 2003; Palmer 2004; Tosun 2000). The situation is further exacerbated because they lack the subject knowledge required of them when the science content is too difficult (Harlen and Holroyd 1997; Murphy et al. 2007; Osborne, Simon and Collins 2003).

This lack of confidence has ramifications for classroom practice, as there is a tendency for teachers to find coping strategies such as relying upon more didactic 'chalk and talk' and rote learning methods or use of worksheets and text books rather than enquiry-based approaches (Appleton and Kindt 1999; Harlen and Holroyd 1997). Effective enquiry-based lessons require teachers to have a range of expertise that includes subject matter content knowledge, pedagogical content knowledge and curriculum knowledge (Guilbert 2002; Gustafson MacDonald and d'Entremont 2007; Parker 2004; Shulman 1986). These are daunting requirements even for trained science teachers because teaching enquiry-based science requires 'a myriad of constantly changing teacher roles that demands more active and complex participation than that suggested by the commonly used metaphor of teacher as facilitator' (Crawford 2000, 935; Crawford 2007). It is therefore unsurprising that enquiry-based work is regarded as one of the most challenging tasks for many primary teachers, and is frequently avoided or taught ineffectually (Kim and Tan 2011). Lack of confidence, coupled with low levels of curricular expertise, can result in enquiry-based science equated to i.) 'hands-on' but not 'minds on' science (Crawford,2000); ii.) fair testing (Turner 2012) and iii) observation (Abd-El-Khalick et al. 2004). Children therefore do not develop the knowledge and skills to increase their understanding of enquiry and scientific literacy.

Developing these enquiry-based skills from the early years of education onwards is crucial if children are to become independent learners with the ability to work cooperatively, share and question their own and others' ideas, as well as evaluate outcomes based on evidence. These higher order thinking skills are not only relevant to learning science but are inherently part of good early years practice that aims to develop positive attitudes to learning by encouraging children's motivation to learn, through stimulating their curiosity, imagination and ability to concentrate (Bowman, Donovan and Burns 2001; Ofsted 2015; Siraj-Blatchford et al. 2008). However, even though children do not come to school as a *tabula rasa*, neither can it be assumed that they are able to manage enquiry-based science without progressively practising the skills required (Harlen 2000; Turner 2012). Thus scientific skills require nurturing in young children and they need to have plenty of opportunities to develop their nascent skills and abilities through activities that promote and extend their interest in the world through stimulated play, exploring and observing natural phenomena and everyday experiences. As a result of such explorations children will be able to describe what they have noticed, albeit with everyday rather than scientific vocabulary, begin to develop questions they would like to answer and then make more accurate observations, possibly using simple equipment or performing tests in order to collect data through drawing, measuring, and describing. Making sense of this data through establishing patterns and relationships will help children make tentative explanations which they can share and discuss with others. This may lead them to modify their ideas by listening to and thinking about new evidence.

Young children cannot be expected to achieve this alone and the teacher therefore has an important role in managing children's scientific development and enabling them to make progress. Guiding and scaffolding children's learning (Vygotsky 1962), ensuring the children have agency and are actively engaged not only strengthens their sense of ownership but also enhances motivation and self-efficacy (Schraw, Crippen and Hartley 2006; Lin, Hong and Cheng 2009; Ryan and Grolnick 1986). Working together and having opportunities to discuss in small groups, with the teacher and the whole class, promotes sense-making and enables children to engage in group work and scientific dialogue, which is regarded as important in facilitating the development of scientific literacy (Osborne and Dillon 2008; Osborne, Eduran and Simon 2004). Yet difficulties of managing group work has been identified as one of the barriers teachers encounter when implementing enquiry-based mathematics and science lessons (Anderson 1996; 2002). Some of this may be due to practical limitations such as physical space, lack of time for science, the norms of interaction in schools and classrooms, large numbers of pupils, lack of resources, and the absence of trained laboratory assistance (Murphy et al. 2007; Singer et al. 2000). However, a crucial factor in putting collaborative group work into practice is likely to be the low proficiency in scientific content knowledge and pedagogical understanding, leading to a lack of confidence in dealing with the discourse practices required for effective enquiry-based science (Harlen and Holroyd 1997).

Furthermore, lack of confidence can lead to a lowering of self-efficacy and create a vicious circle in which the teacher's sense of competence is reduced so that they may avoid teaching science or adopt teacher-led and controlled pedagogies that leave little room for student autonomy and active engagement in science (Appleton 1995; Kim and Tan 2011; Palmer, 2004). However, if this cycle can be broken by teachers relinquishing control, or 'letting go' they may become more enthusiastic and confident about teaching science. As a result, this may mean that more time is spent on enquiry-based science experiences that encourage student-led activities (Hodson 2002).

This paper reports on the experience of one infant school teacher who did 'let go' despite concerns about enquiry-based science. In doing so it adds to the literature with respect to how enquiry-based science can be facilitated and the impact this has on teaching and learning science. The main aim of the research addressed in this paper was to explore what facilitates enquiry-based science in the infant classroom, and what challenges are encountered.

Methodology

Teachers taking part in the Pri-Sci-Net project were asked to trial science activities developed by the project team with the purpose of determining the extent to which these activities encouraged enquiry-based science. Alongside these trials the teachers were involved in 20 hours of training about enquiry-based science, which involved face-to face sessions with teachers trying out the activities for themselves and then using them in the classroom prior to another face-to face session. In this way they became familiar with the Pri-Sci-Net approach to enquiry-based science. Two different activities were trialled in the infant class in this study; these were:

The world around us: exploring shadows, day and night

This activity involved the exploration of how shadows are produced by investigating the shadows made by different objects and observing shadows over the course of a day. The first investigation involved children enquiring about the shape, size and colour of shadows. The second focused on how the shadow of an object changed during the course of a day.

Magnetic Power

This activity explored magnetic and non-magnetic materials and the relative strength of different magnets. The children had opportunities to develop their ideas about magnetic and non-magnetic materials by exploring different materials. They were then encouraged to explore the strength of different magnets and design their own investigation to measure the strength of different magnets.

The research took place in an infant classroom of thirty children (ages 5-7 years) who all took part in both of the activities at the beginning of the school year, i.e. October. The school is in an urban low socioeconomic area with an intake of children of mainly white British ethnic origin with relatively low academic attainment levels.

The classroom teacher has 20 years' experience and had recently taken on the role of science coordinator for the infant school. She is enthusiastic about science and during her pre-service training studied science as a specialist subject. She was keen to participate in the trials and deliver more enquiry-based science in her classroom and volunteered to be one of the teachers observed in the project. She maintained that doing this would help her reflect on her practice and empower her to extend her pedagogy and interest in child-centred learning.

In order to obtain data that were as ecologically valid as possible, the activities took place as part of the normal school day, with their normal teacher and in the children's usual classroom (and playground with respect to the shadows activity). However, there was no expectation that the teacher had to follow the pre-designed activities precisely as they were meant to act as a guide rather than a prescriptive document, and the teacher was aware that they could be adapted to suit the needs of the children in their class.

Ethical permission to undertake the research was granted by the University of Southampton Ethics Committee. The research procedures and this manuscript adhere to The Ethical Code for Early Childhood Research (EECERA 2014). Participation in the research was voluntary and informed consent was gained from the parents/guardians of all children participating in the interviews. The teacher and the children were assured that their responses were confidential and anonymous. All audio recordings were transcribed and the recordings and transcripts stored securely and anonymously. All other documents were digitised and also stored securely and anonymously.

Data collection and analysis

A mixed method approach was adopted including quantitative and qualitative data collection. This enabled a variety of perspectives about the activities to be gained during the trials by employing non-participant classroom observations, interviews with the class teacher, and a brief structured focus group interview with different groups of children shortly after each activity took place. The research tools were designed to elicit data concerning how the teacher and children participated in the enquiry-based activities, with respect to engagement, enjoyment and the extent to which the teacher adopted a child-centred approach that facilitated student autonomy during the activities.

Classroom observations

The classroom observation tool was developed in conjunction with all partners involved in Pri-Sci-Net and based on the vision for enquiry-based science. The extent of enquiry-based science was gauged in the classroom observations based on the level of autonomy, the overarching principle of the Pri-Sci-Net framework, the children had on a scale of 1-3, where

1=least independent level (teacher-led) and 3=children working independently (child-led) with 2=teacher-guided or a combination of teacher-led and child-led. The scores were related to levels of self-regulation (Rylander, 2012). This scale was applied to the following seven criteria that are adapted and elaborated from the Pri-Sci-Net framework, for each activity, so that different aspects of the lesson could be evaluated as well as making an overall judgment about each activity:

1. Children are engaged by scientific questions (Pri-Sci-Net framework point 2, 3 and 5)
2. Children are actively engaged in the learning process with emphasis on observations (Pri-Sci-Net framework point 1 and 5)
3. Children develop descriptions, explanations and predictions using evidence (Pri-Sci-Net framework point 3 and 5)
4. Children give priority to evidence as they plan and conduct investigations ((Pri-Sci-Net framework point 2 and 5)
5. Children connect evidence and explanations to developing scientific knowledge (Pri-Sci-Net framework point 2 and 5)
6. Children interact with each other during the enquiry activity (Pri-Sci-Net framework point 4 and 5)
7. Children engage in critical discourse with others about procedures, evidence and explanations (Pri-Sci-Net framework point 4 and 5)

Observations were completed by two researchers independently, and the scores and comments were discussed after the lessons in order to reach agreement.

Quantitative observation scores were collated (see Table 1) and the qualitative comments for each criterion were amalgamated.

Teacher interviews

The classroom teacher was interviewed twice during the trials soon after each activity had taken place. The immediacy of the interviews enabled a contemporaneous account of each lesson which was thought to be advantageous in reducing problems of recall and self-censorship (Bryman 2012). The teacher was asked about the general acceptability of the activity and then more specifically about enquiry-based science, finally questions about any problems that arose were explored. The specific details can be found in Appendix 1.

Both interviews were transcribed verbatim and thematically analysed (Braun and Clarke 2006) using qualitative data analysis software.

Children's focus groups

Immediately after each activity a small group of children (3 for *Magnetic power* and 5 *The world around us: exploring shadows, day and night)* were asked about what they thought of the lesson in particular and what they had enjoyed/not enjoyed. Specific details of the questions can be found in Appendix 2. The children's answers were categorised according to the questions that were asked.

Findings

The findings from each data source are presented in order to address the research aim: to explore what facilitates enquiry-based science in the infant classroom, and what challenges are encountered.

The observation findings (Table 1) indicate that overall, both lessons were a mixture of child and teacher-led elements with some aspects of each activity being more child-led than others. For both lessons the most teacher-led element; *Children are engaged by scientific questions* meant that the children tended to be directed to a question rather than developing their own. The most child-led element of both lessons; *Children interact with each other during the enquiry activity* was apparent in their talk and behaviour. The lesson on magnetic power provided greater autonomy for the children with a mode score of 3, indicating that the children were able to undertake the majority of the activity independently. The mode score of 2 for the shadow activity suggests more teacher control. However, observation comments indicate that this lesson overall was more inclined towards a combination of teacher-and child-led. These results indicate that this teacher did have the confidence to relinquish control of the investigation and as a result the children began to develop autonomy and self-regulation through these experiences.

As the teacher reflected on the outcome of each activity during the interviews, she was clearly convinced of the value of an enquiry-based approach to learning science, in helping children to develop scientific skills, understand how science works, and facilitate more in-depth thinking and learning. As a consequence, she considered the approach would encourage children's interest and enthusiasm in science. She noted (see below) that having engaged with the activities she would employ more enquiry in her science lessons in the future. Importantly, she also understood the value of this approach for all children to learn science, not just the more able.

‘[Investigative work was] very evident. I think they were definitely developing predictions, gathering evidence, working with each other. It was very open-ended. And even with the mixed abilities, I did think it was quite good because even the less able and the younger children were able to access it really. They could try it out…. The children were very engaged and excited. The activity allowed them to become self-directed or independent learners, because they questioned each other, and started to think about what other people were saying. I think it has an impact on their self-concept, and learning science, because you’re talking about skills, and scientists need to have evidence and proof, so it’s them thinking that they are scientists. It also really developed their metacognitive skills, there was a lot of that going on.’

Data from observation comments, teacher interviews and children’s responses have been amalgamated thematically with respect to the findings and how they pertain to key features of enquiry-based science. These sections presented below provide further detail about how enquiry-based science was facilitated in these lessons.

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Opportunities to explore, be creative and curious

Children had the freedom to explore a range of ideas and decide what to do in both lessons. At the start of each lesson, the teacher introduced the topic and questioned the children to stimulate their interest and curiosity and enable them to think about what they might like to investigate. Even though the magnetic power activity was initially more open-ended with the children deciding for themselves what they thought was important to find out about magnets, they were clearly interested and enthusiastic in the shadows activity and this stimulated their curiosity to develop their ideas in order to find out more. For example, the children observed the change in length of the shadows whilst they were outside and were keen to talk about this and think about what it might look like later in the day.

The teacher indicated afterwards that she was pleasantly surprised how well the shadows investigation had gone. She appreciated the importance of enabling the children to explore and investigate yet showed some concern that the children had not developed their conceptual understanding as much as she had expected. This was possibly due to limited time and the teacher adhering strictly to the activity format. However, it was encouraging to see that her solution for future lessons would be to include more time for further investigations to support the children's understanding rather than simply informing them of the right answer:

'I was quite pleased, because they were all engaged, and interested. They love being outside. I think it was highly investigative …. the only trouble was we ran out of time on that, and we haven't been able to follow it up, so it was just a shame because they were really getting into it, and we needed a little bit longer really, or another lesson on it. We needed more time; ideally I would have done another lesson consolidating what they did. Because I am not sure if they really all got the idea that it is the solid object blocking the light and making the shadow. It would have been better if we got that really clear first. But definitely, really good investigative work.'

Hands-on minds-on

As each lesson progressed the children were actively engaged, both physically and mentally. During the shadows activity they were able to run around the playground and explore their shadow. The novelty of this experience may have increased their enjoyment and made them less aware of the teacher but this autonomy appears to have aided their investigative skills. They were keen observers and some made accurate observations about what their shadow looked like and how it changed shape when they moved. As a result of her observations this child also began to consider how shadows are formed:

'…. the shadows are keeping the [light?] …because the shadows don't come away from you till night time.'

Similarly, during the magnets activity, the freedom to explore and find things out for themselves meant that this child observed differences between the poles of bar magnets. He was also aware that he was doing science and that this was an enjoyable lesson, as he commented:

'I thought that some of my magnets didn't really work, and some magnets did…. and I worked out that some magnets, some magnets are not really very good at sticking to each other [he was exploring the poles of the magnets] …and I enjoyed the science lesson.'

Trying things out for themselves meant that the children began to make predictions on the basis of their observations. During the magnets lesson, the children planned and designed their own investigations and this led to keen observations about what materials and objects magnets will attract and also how strong different magnets are. This was very successful to the extent that some children started making predictions about what the strongest magnet would be. For example, some children thought that the biggest magnets would be the strongest and began to investigate their ideas as this child's comments about what his group did during the lesson indicates:

'[I enjoyed it] When I was learning science things, and I, we haven't done science for a very long time. And we were getting a ruler and we were using this big magnet and small magnet, and we put something [paperclips] down at the bottom [of the ruler] and then we counted down back to zero, and then it [the paperclip] would come up. And that's what we learnt today.'

Discuss and explain what has happened

As a result of engaging with the activities the teacher acknowledged the value of enabling the children to carry out their own investigation as the enquiry-based approach advocated in the activities which she adopted not only gave them practice at a range of process skills, but also encouraged them to think scientifically and develop their ideas:

'I think it's good because it [requires] quite a lot of skills; it's all that planning together, working together; thinking about what will happen. And they were making predictions. I think it is quite good for them, actually moving them on and thinking about actually how are we going to prove this, which I think is fantastic, because [at first] they couldn't work out how to test it. When I said, "Well what are you going to do"? …. It got them thinking.'

The children discussed their ideas throughout the lesson, and at the end of each lesson they were brought together as a whole class for a plenary session, where they had time to explain to each other what they had done and found out. The teacher's comments and questioning throughout the lesson and during the plenary gently guided the children to more elaborate explanations to focus their thinking about investigative work and appropriate levels of evidence, for example: 'Why should we not take our object away after the first measurement?' In this way the teacher tried to elicit from the children what they had found out, and what they had done rather than expecting a ‘right’ answer or telling them what they found out. However, the teacher reflected that perhaps she had been more prescriptive than she would have ideally preferred as she directed questions and reiterated key vocabulary to consolidate learning. She went on to consider that rather than expect children to understand new and specific scientific vocabulary in the abstract, the best approach would be for them to practically experience what the terms actually mean, as she explained:

‘They didn’t really understand what evidence is? They said: “What is evidence”? What is proof? I have used it, but we haven’t really done a lesson which has addressed that, and this activity did. And if we followed it up again with a bit more measuring then we could say, well this time we have got some definite proof.’

The more direct approach she adopted may be due to unfamiliarity with this way of working in science on the part of both the children and the teacher and indicated the need for more opportunities to practice undertaking investigations, which she recognized as the most appropriate pedagogical approach.

Unfamiliarity with collaborative work was also evident. By virtue of having the freedom to explore, the children were able to interact with one another and engage in dialogue about what they were finding out. However, some groups tended to split up, with children working in pairs rather than the groups the teacher had put them in. This may be due to the age of the children and not yet understanding the nature of group work, e.g. taking turns to talk, and this was mentioned by the children:

‘And a little bit with my group because some of them were being a little bit silly, and they were having trouble being like a team. And so we had a little bit of trouble, and I was the team leader and I was quite, I was quite confused about everything.’

That said, whether the discussion was with one other child or at the end of the lesson during a whole class plenary session, the children did lead the conversations and had the space to talk and share their ideas.

Time and curriculum pressures

The teacher also acknowledged that investigative work is time-consuming and requires teachers to have the confidence to adopt a children-centred approach that provides adequate opportunity to complete each aspect of the investigation fully, rather than feeling under pressure to intervene, as she realised that the former approach helps to maximise children's learning:

'During the activity I thought I would speed it up a bit. Having to work in a group and plan first, I thought I might not have done that for so long myself. But it's actually quite useful for them to think about what they're going to do. Because quite a lot of them didn't really have a plan with the time they had. So it was quite a good thing for them to start doing that, and do it in a bit more depth, trying to think a bit harder about what they were going to do with the test. And not being provided with the answers.'

Similarly, she recognized the pressure to ensure that the curriculum is covered and that the children know about certain concepts. Therefore, there is a temptation to try to consolidate learning in a less investigative manner. At the beginning of the shadows activity the teacher referred to their previous lesson and then structured what the children were to do on the basis of their comments. After this lesson the teacher reflected on her approach and she considered that the lesson would have been improved if the children had more time to explore for themselves rather than be guided through an initial discussion as this may have generated more ideas and been less prescriptive. She also acknowledged that she may have under estimated the children's understanding:

'In the past, shadows seemed quite a tricky thing to do practically, so it was really nice to be able to think how we could use the outside and how shadows change over the day, which I have never done before…. Next time I might take them outside and look at the shadows first, a little bit more, beforehand …we talked about it before the investigation phase, so more exploration first. We perhaps need to do more of that with the children, is what it made me think. Sometimes you take it back too low.'

Discussion and concluding comments

Whilst there were differences in the levels of autonomy and self-direction between the two lessons, the findings indicate that the principles within the vision for enquiry-based learning in science were achieved to a large extent and this was due to the teacher 'letting go' and having the confidence to relinquish direct control rather than employ a didactic pedagogy (Appleton and Kindt 1999). Unlike the findings of Osborne and Dillon (2008) these infants were actively engaged in authentic and problem-based learning activities that had a clear focus on observations and experiences as sources of evidence, whilst they had opportunities to develop other scientific process skills and engage with each other in discursive argumentation that are essential goals for early years science education (DfE 2014a; DfE 2014b; National Research Council 2000; Poisson 2000).

As a result of the teacher's pedagogical approaches genuine enquiry-based science was facilitated and encouraged that had positive outcomes for both the children and the teacher. The freedom to explore meant that the children's curiosity, enjoyment and creativity were developed which also led to greater understanding of the phenomena they were exploring; indicating that they were both physically and mentally engaged (Crawford 2000). However, enabling children to engage in developing their own scientific questions appeared to be more problematic as the teacher tended to lead this aspect of both lesson activities. A future challenge for the teacher will be to facilitate the children to develop their own questions rather than direct them and this like other scientific skills requires practice (Harlen 2000; Turner 2012). As young children naturally engage in their own enquiries, these can be capitalised upon by the teacher by building on children's own questions to maintain their engagement with science (Ellis and Kleinberg 1997).

The lesson on magnetic power seemed to be more child-led and this may have been due to it being the second activity that was trialled. The teacher's confidence may have increased as a result of positive experiences with the shadows activity resulting in greater enthusiasm and increased opportunities for investigative work (Hodson 2002). It was also the first of a sequence of lessons on magnets and the children were engaged in an open-ended activity to investigate and discover what they could about magnets rather than being directed to undertake a particular investigation. On the other hand, the children had already done some work on shadows and the teacher seemed to want to elicit their knowledge to consolidate learning and ensure the second lesson would provide the correct level of challenge, thus adhering to key principles of constructivist pedagogy (Driver 1993; Harlen 2000). However, after the lesson the teacher did recognise the value of more open-ended explorations, which she acknowledged she would include in her future practice. She considered that this would give children more opportunities to develop their ideas further at their own level rather than presuming their level of understanding, which is often higher than the teacher assumes (Gilbert, Osborne and Fensham 1982).

Ownership of learning is an important aspect of effective enquiry-based science as it enables children to gain confidence and mastery of working scientifically and understanding the nature of science (Osborne and Dillon 2008). This seems to have been achieved in both activities, to the extent that the children in this study were able to develop their ideas and find out more about each phenomenon. Furthermore, enabling young children to develop their interest and enthusiasm for science is a crucial benefit of an enquiry-based approach because it can further children's continued interest in science by tapping into their innate curiosity (Bell et al. 2010; Ellis and Kleinberg 1997; Rocard 2007). This is especially important at this young age as children naturally engage in enquiry and telling stories about their experiences can help them make sense of the world (Ellis and Kleinberg, 1997). During both activities, the children were highly engaged and enthusiastic, their interest and curiosity was piqued, and they offered ideas and explanations for what they had observed.

However, at times the teacher did tend to lead the children to form 'accurate' explanations. This may have been due to the age of the children and their lack of literacy skills but also, as she explained, the children were not entirely familiar with this mode of working in science. Rather than lacking confidence and reverting to more didactic methods (Appleton and Kindt 1999) she was convinced that the children required more practice and greater involvement in their own investigations. Therefore, she considered that including more enquiry in science lessons was vital for effective learning in science (Gatt and Vella 2003). Furthermore, as Murphy et al. (2007) note time is frequently cited as a barrier to implementing enquiry, and young children need extensive time to explore and observe (Ellis and Kleinberg 1997). This teacher acknowledged her surprise about the amount of time required for children to engage in enquiry-based science. However, running out of time may in part have been as a result of her following the activity format precisely rather than adapting it to the needs of the children in her class. Whist this was not an essential requirement she may have felt it incumbent upon her to do so as this was a trial of the activities. Being observed can also affect someone's pedagogic practice and even though there was a good rapport between the researchers and the teacher she may felt more comfortable in adhering to 'the script'. Enabling young children to become independent learners is part of good early years practice and this teacher was convinced that the children required the time to investigate and develop their own ideas. She thought doing so would be more effective in maximising their learning rather than directly intervening to provide 'the right answer' (Bowman, Donovan, and Burns 2001; Ofsted 2015; Siraj-Blatchford et al. 2008). Reflecting on future adaptations to her pedagogical practice, despite the pressures of completing an over-crowded curriculum, she indicated that she would have the confidence to exercise self-control not to intervene too quickly but to act as a facilitator for children's learning (Crawford 2000; Crawford 2007).

The findings also highlighted the need for skills such as such as speaking, listening, turn taking, planning, decision making and trusting each other, which help to facilitate worthwhile collaborative group work and productive dialogue. It is not surprising that the children found group work difficult even though the teacher had allocated them particular roles within their groups. As Anderson (1996; 2002) points out, this is one of the major difficulties in implementing effective enquiry-based approaches and yet it is a vital factor in facilitating the development of scientific literacy (Osborne and Dillon 2008). Group work also contributes to improving scientific process skills and learning more generally by refining understanding through discussion, offering opportunities for reflection and feedback, increasing communication and higher order thinking skills, and enabling more complex problems to be tackled through sharing with others (Caruso and Wooley 2008; Larkin 2006; Slavin, Hurley, and Chamberlain 2003). Therefore, it is essential that collaborative group work is introduced and fostered from an early age to ensure the benefits of this way of working are maximised. This research confirms that this aspect of enquiry-based science is difficult but that with close support and teacher confidence it is possible for even very young children to work independently in groups. Furthermore, if group work or any other aspect of enquiry-based science is to be effective and of benefit to children's learning, it needs to be systematically planned and consideration needs to be given to ensure that skills and concepts are dealt with in a progressive manner.

As we reflect on the trial of these activities it is essential that teachers are made more aware that the materials are meant to be used as flexible guides for enquiry-based science rather than a prescriptive text. However, we recognise the need for additional advice about the timing of the activities, together with further guidance about how to organise and manage group work with young children. Nonetheless, the findings of this examination of one teacher's practice do show that, despite the challenges such as time, curriculum pressure and managing group work effectively, when a teacher has the confidence to adopt a child-centred approach in which young children investigate scientific phenomena for themselves they are quite capable of engaging in enquiry-based science at a sophisticated level. Furthermore, their learning and understanding of science is enhanced by the freedom and autonomy that genuine enquiry-based learning appears to have encouraged. However, for enquiry-based science to be an automatic, embedded approach to teaching and learning, teachers do need to have the courage, like the teacher in this study, to 'let go'. In relinquishing control, this teacher's pedagogical repertoire was developed and this appears to have had a positive effect on her self-confidence and self-efficacy so that she is more likely to continue to include enquiry-based science in the future (Hodson 2002). Whilst this is a small scale study and therefore lacks generalisability should others follow this teacher's example as a model for enquiry-based science the children they teach will be the beneficiaries.

References

Abd-El-Khalick, F. and V. L. Akerson. 2004. Learning as conceptual change: factors mediating the development of pre-service elementary teachers' views of the nature of science. *Science Teacher Education* 88 (5): 785-810.

Anderson, R. D. 1996. *Study of curriculum reform*. Washington, DC: U.S. Government Printing Office.

Anderson, R. D. 2002. Reforming Science Teaching: What Research Says About Inquiry. *Journal of Science Teacher Education* 13 (1): 1-12.

Appleton, K. 1995. Student teachers' confidence to teach science: Is more science knowledge necessary to improve self-confidence? *International Journal of Science Education* 17 (3): 357-369.

Appleton, K., and I. Kindt. 1999. Why teach primary science? Influences on beginning teachers' practices. *International Journal of Science Education* 21 (2): 155-168.

Appleton, K., and I. Kindt. 2002. Beginning elementary teachers' development as teachers of science. *Journal of Science Teacher Education* 13 (1): 43- 61.

Bartley, J. E., Mayhew, L. M., and N. D. Finkelstein. 2009. "Promoting Students' Understanding and Interest in Science through Informal Science Education." In Volume 1179 of *Physics Education Research Conference*, edited by Sabella, M., Henderson, C. and C. Singh, 93-96.

Bell, T., Urhahne, D., Schanze S. and R. Ploetzner. 2010. Collaborative Inquiry Learning: Models, Tools and Challenges. *International Journal of Science Education* 32 (3): 349–377.

Bowman, Barbara T., Donovan, M. Suzanne, and M. Susan Burns, eds. 2001. *Eager to Learn: Educating our Preschoolers*. Washington, DC: National Academy Press.

Braun, V., and V. Clarke. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3 (2): 77-101.

Bryman, A. 2012. *Social Research Methods*. 4th ed. Oxford: OU Press.

Caruso, H. M., and A. W. Wooley. 2008. Harnessing the Power of Emergent Interdependence to Promote Diverse Team Collaboration. *Diversity and Groups* 11: 245-266.

Crawford, B. A. 2000. Embracing the Essence of Inquiry: New Roles for Science Teachers. *Journal of Research in Science Teaching* 37 (9): 916-937.

Crawford, B. A. 2007. Learning to Teach Science as Inquiry in the Rough and Tumble of Practice. *Journal of Research in Science Teaching* 44 (4): 613-642.

Department for Education. 2014a. *The Statutory Framework for Early Years Foundation Stage*. DfE: Cheshire.

Department for Education. 2014b. *Science Programmes of Study: Key Stages 1 and 2*. DfE: Cheshire.

Driver, R. 1993. *The Pupil as Scientist?* Milton Keynes: Open University Press.

Ellis, S., and S. Kleinberg. 1997. Helping teachers support young children in science enquiries. *Education 3-13* 25(3): 59-64. doi: 10.1080/03004279785200361

EECERA. 2014. *The Ethical Code for early Childhood Research*. www.eecera.org

Engel, S., and K. Randall. 2008. How Teachers Respond to Students' Inquiry. *American Educational Research Journal* 46 (1): 183-202.

Gatt, S. and Y. Vella, eds. 2003. *Constructivist Teaching in Primary School: Examples in Social Studies, Science, Mathematics, Design and Technology and ICT.* Malta: Agenda Publishers.

Gilbert, J. K., Osborne, R. J. and P. J. Fensham. 1982. Children's Science and its Consequences for Teaching. *Science Education* 66 (4): 623-633.

Guilbert, S. 2002. Teaching Elementary Science: A Complex Task. *Alberta Science Education Journal 34 (1)*: 18–25.

Gustafson, B., MacDonald, D. and Y. d'Entremont. 2007. *Elementary Science Literature Review: for Caroline Nixon and Francois Lizaire*. Alberta: Alberta Education, Curriculum Branch.

Hanson, D., and V. Akerson. 2006. Will an Improved Understanding of Nature of Science (NOS) Improve Elementary Teachers' Self-Efficacy for Science Teaching? A Call for Research. *Alberta Science Education Journal* 38 (1): 6–11.

Harlen, W. 2000. *The Teaching of Science in Primary Schools*. London: David Fulton Publishers Ltd.

Harlen, W. and C. Holroyd. 1997. Primary teachers' Understanding of Concepts of Science: Impact on Confidence and Teaching. *International Journal of Science Education* 19 (1): 93-105.

Hodson, D. 2002. Countering Science Reluctance in Elementary Science Education: Contrasting Approaches via Action Research. *Canadian Journal of Science, Mathematics and Technology Education* 2 (3): 305–320.

Jarrett, O. S. 1999. Science Interest and Confidence among Preservice Elementary Teachers. *Journal of Elementary Science Education* 11 (1): 49–59.

Kim, M., and A. L. Tan. 2011. Rethinking Difficulties of Teaching Inquiry-Based Practical Work: Stories from Elementary Pre-Service Teachers. *International Journal of Science Education* 33 (4): 465-486.

Larkin, S. 2006. Collaborative Group Work and Individual Development of Metacognition in the Early Years. *Research in Science Education* 36 (1-2): 7-27.

Lawson, A. 2003. The Nature and Development of Hypothetico-Predictive Argumentation with Implications for Science Teaching. *International Journal of Science Education* 25 (11): 1387-1408.

Lin, H., Hong, Z. and Y. Y. Cheng. 2009. The Interplay of the Classroom Learning Environment and Inquiry-Based Activities. *International Journal of Science Education* 31 (8): 1013–1024.

Lloyd, J. K., Smith, R. G., Fay, C. L., Khang, G. N., Wah, L. L. K., and C. L. Sai. 1998. Subject Knowledge for Science Teaching at Primary Level: A Comparison of Preservice Teachers in England and Singapore. *International Journal of Science Education* 20 (5): 521–532.

Meltzoff, A. N. 1990. "Towards a developmental cognitive science." In *The development and neural basis of higher cognitive functions*, edited by A. Diamond. New York: Annals of the New York Academy of Sciences.

Piaget, J. 1954. *The construction of reality in the child*. New York: Basic Books.

Mulholland, J. and J. Wallace. 2003. Facilitating Primary Science Teaching: A Narrative Account of Research as Learning. *Teachers and Teaching: Theory and Practice* 9 (2):133-155.

Murphy, C., Neil, P., and J. Beggs. 2007. Primary Science Teacher Confidence Revisited: Ten Years On. *Educational Research* 49 (4): 415-430.

National Research Council. 2000. *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning*. Washington, D.C.: National Academy Press.

Office for Standards in Education (Ofsted). 2015. *Handbook for Inspecting Schools in England*. Manchester: HMSO.

Osborne, J., and J. Dillon. 2008. *Science Education in Europe: Critical Reflections*. London: Nuffield Foundation.

Osborne, J., Erduran, S., and S. Simon. 2004. Enhancing the Quality of Argumentation in School Science. *Journal of Research in Science Teaching* 41 (10): 994-1020.

Osborne, J., Simon, S., and S. Collins. 2003. Attitudes Towards Science: A Review of the Literature and its Implications. *International Journal of Science Education* 25 (9): 1049–1079.

Palmer, D. 2004. Research Report Situational Interest and the Attitudes towards Science of Primary Teacher Education Students. *International Journal of Science Education* 26 (7): 895-908.

Parker, J. 2004. The Synthesis of Subject and Pedagogy for Effective Learning and Teaching in Primary Science Education. *British Educational Research Journal* 30 (6): 819–839.

Parker, J., and E. Spink. 1997. Becoming Science Teachers: An Evaluation of the Initial Stages of Primary Teacher Training. *Assessment and Evaluation in Higher Education* 22 (1): 17-31.

Poisson, M., ed. 2000. *Science Education for Contemporary Society: Problems, Issues and Dilemmas*. *Final Report of the International Workshop on the Reform in the Teaching of Science and Technology at Primary and Secondary Level in Asia: Comparative References to Europe. Beijing, China, March 27-31, 2000*. International Bureau of Education/The Chinese National Commission for UNESCO.

Rocard, M. 2007. *Science Education Now: A Renewed Pedagogy for the Future of Europe*. Office for Official Publications of the European Communities.

Ryan, R. M., and W. S. Grolnick. 1986. Origins and Pawns in the Classroom: Self-report and Projective Assessments of Individual Differences in Students' Perceptions. *Journal of Personality and Social Psychology* 50 (3): 550–558.

Rylander, J. 2012. "Using Levels of Inquiry in the Classroom." Chap 1 in *Cases on Inquiry Through Instructional Technology in Math and Science*, edited by L. Lennex, 1-19. IGI Global.

Schraw, G., Crippen, K. J., and K. Hartley. 2006. Promoting Self-Regulation in Science Education: Metacognition as Part of a Broader Perspective on Learning. *Research in Science Education* 36 (1-2): 111-139.

Singer, J., Marx, R. W., Krajcik, J. and J. C. Chambers. 2000. Constructing Extended Inquiry Projects: Curriculum Materials for Science Education Reform. *Educational Psychologist* 35 (3): 165-178.

Siraj-Blatchford, I., Taggart, B., Sylva, K., Sammons, P. and E. Melhuish. 2008. Towards the Transformation of Practice in Early Childhood Education: The Effective Provision of Pre-School Education (EPPE) Project. *Cambridge Journal of Education* 38 (1): 23-36.

Shulman, L. S. 1986. Those Who Understand: Knowledge Growth in Teaching. *Educational Researcher* 15 (1): 4-14.

Stevens, C., and G. Wenner. 1996. Elementary Preservice Teachers' Knowledge and Beliefs Regarding Science and Mathematics. *School Science and Mathematics* 96 (1): 2–9.

Slavin, R., Hurley, E. A. and A. Chamberlain. 2003. "Cooperative Learning and Achievement: Theory and Research." In *Handbook of Psychology: Educational Psychology*, edited by W. M. Reynolds and G. E. Miller, 177–198. New York: Wiley.

Tosun, T. 2000. The Beliefs of Preservice Elementary Teachers towards Science and Science Teaching. *School Science and Mathematics* 100 (7): 374-379.

Trundle, K. C., Atwood, J. E., and R. K. Christopher. 2002. Preservice Elementary Teachers' Conceptions of Moon Phases before and After Instruction. *Journal of Research in Science Teaching* 39 (7): 633-658.

Turner, J. 2012. It's Not Fair. *Primary Science* 121: 30-33.

Van Zee, E., Lay, D., and D. Roberts. 2003. Fostering Collaborative Inquiries by Prospective and Practicing Elementary and Middle School Teachers. *Science Education* 87 (4): 588–612.

Vygotsky, L. S. 1962. *Thought and Language*. Cambridge, Mass.: MIT Press.

Wang, F., Kinzie, M. B., McGuire, P., and E. Pan. 2009. Applying Technology to Inquiry-Based Learning in Early Childhood Education. *Early Childhood Education Journal* 37(5): 381-389.

Appendix 1

Teacher interviews

General acceptability of the activity:

1. Overall, how well do you feel the activity applies to this age group?

Specific to enquiry-based science:

2. How evident is enquiry-based science part of this activity?
3. Did you feel that the children were engaged in the activity?
4. To what extent did you feel that the activity was authentic and relevant to the children?
5. To what extent do you feel that the children were involved in:
    a. Developing the predictions?
    b. Gathering evidence?
    c. Using that evidence to draw conclusions?
    d. Discussion

    e. Working with each other

Problems:

6. Will you use these activities again?
    a. What modification do you think you will be making?
    b. What did you find were its particular strengths and weaknesses?
7. What kind of problems and/or obstacles did you have to overcome while using the activity in your classroom?

Appendix 2

Children's focus groups

1. Did you enjoy the activity? What did you like? What not?
2. Are you used to do science activities in this way?
3. Was it difficult to follow and carry out the activity?
4. Where there any words, expressions you did not understand?
5. Did you like the way you could share ideas?

Table 1. Observation scores of enquiry-based criteria per activity

(1= least independent level (teacher-led); 2=teacher guided or combined teacher-led and child-led; 3 = students doing this aspect independently)

Activity	Enquiry-based criteria						
	1.Children are engaged by scientific questions	**2. Children are actively engaged in the learning process with emphasis on observations**	**3. Children develop descriptions, explanations and predictions using evidence**	**4. Children give priority to evidence as they plan and conduct investigations**	**5. Children connect evidence and explanations to developing scientific knowledge**	**6. Children interact with each other during the enquiry activity**	**7. Children engage in critical discourse with others about procedures, evidence and explanations**
Shadows Day & Night	1	2	1/2	3	2	3	2
Magnetic Power	1/2	3	2	3	2	3	3