

The Journal of Emergent Science

Issue 12 Winter 2016/17

Special Edition!

Outcomes of the Primary Science Teaching Trust's 2016 international Primary Science Conference.

No boundaries, No barriers.



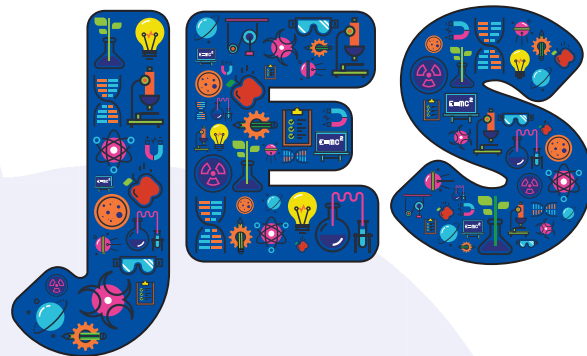
The **Association**
for **Science Education**

Promoting Excellence in Science Teaching and Learning



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Issue 12 Winter 2016/17



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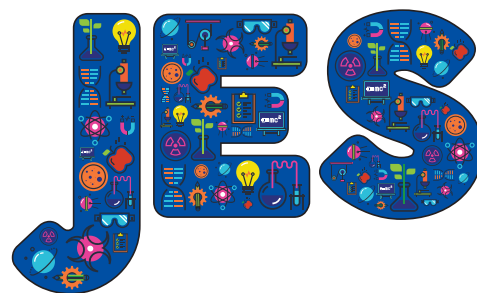
INTERNATIONAL CONFERENCE

NO BOUNDARIES. NO BARRIERS.



Editorial

● Amanda McCrory ● Suzanne Gatt



We welcome you to this special edition of *JES*, which focuses on practitioner research in the Early Years Foundation Stage (EYFS) and primary classroom; and where researchers of science in teacher education share their theoretical approach and experiences in supporting teachers.

Emerging from presentations made at the PSTT International Primary Science Conference, *No Boundaries, No Barriers*, held in Belfast in June 2016, this edition richly demonstrates how evidenced-based research can significantly improve the provision of science in both the EYFS and Key Stages 1 & 2 (ages 5-11). Certainly, eliciting and maintaining curiosity via exploration and inquiry is a strength of EYFS practitioners, which has been well recognised by Ofsted (2013) and is clearly reflected in the articles presented in this issue.

Teachers' professional development is key to bringing about effective change in school science. As many EYFS and primary teachers are aware, implementing inquiry is a great challenge, as it demands the changing of one's own image of science, developing expertise in teaching through inquiry by gradually gaining confidence through practice, and understanding how to use formative evaluation (of personal practice and children's achievement) to improve one's own practice. The journey is long and often time- and energy-consuming. Teaching through inquiry and exploration changes the dynamics of learning. It is not easy to accept working within a framework where there isn't really one correct answer; where you have to refrain from telling and guiding, but instead promote curiosity, inquisitiveness and reflection. And, in addition to all this, you also have

to fulfil all the curriculum demands. The articles in this issue shed light on how teachers were supported, and achieved this shift in different ways and to different degrees. The articles make interesting reading, and we encourage you to give yourself a chance as well as time to allow yourself to go through this change gradually.

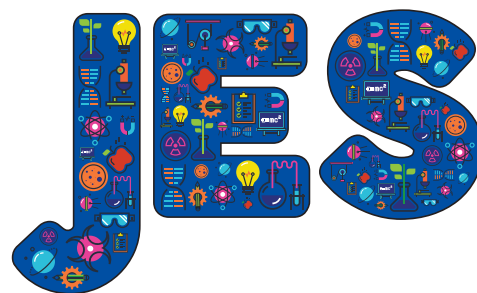
We hope that you will be inspired by the powerful research in this edition of *JES*; firstly, to undertake practitioner research in your own classroom environment which, as you can see from the articles in this issue, is a rewarding experience both for you, in terms of your continuing professional development, and the children whom you teach! We also hope that, if you are inspired to undertake your own research project based in science education, then you will consider sharing your research outcomes with a wider audience by submitting an article to *JES*, which will also enable you to add to the existing and growing literature on teaching science to 0-11 year olds. Details of how to submit an article to *JES* are available on p 116 of this issue.

We would like to take this opportunity to thank the Primary Science Teaching Trust (PSTT), and particularly the Guest Editor, Professor Deb McGregor, for their enormous contribution to this Winter 2016/17 issue. We wish you happy reading and hope to hear about your achievements and experiences.

Dr. Amanda McCrory and **Professor Suzanne Gatt** are Co-Editors of the *Journal of Emergent Science*.
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Guest Editorial



● Prepared by Deb McGregor

A special edition

This bumper edition of *JES* contains a collection of articles for the special edition emerging from the June 2016 International Conference of Primary Science held in Belfast, Northern Ireland. The title of the Conference, *No Boundaries No Barriers*, offered an open forum within which to be creative about the focus of the papers and workshops presented. This inaugural international conference, sponsored by the Primary Science Teaching Trust (PSTT), was well attended by over 380 practitioners, researchers and educationalists working in primary science. The papers included here are all written by teacher-researchers or teacher-education-researchers, with the intention of informing, illuminating or recommending ways to enhance teaching, learning, assessment or leadership of primary science.

Articles focusing on creative practice and the development of literacy and inquiry skills

This special edition begins with the first three papers (Digby, McGregor and McClune) relating to different kinds of practice and the ways in which they support literacy and inquiry skill development with early years, Key Stage 1 (age 5-7) and Key Stage 2 (age 7-11) children.

Digby's paper, *To what extent can Video-Stimulated Reflective Dialogue facilitate the development of practitioner critical reflection and understanding of creativity in scientific inquiry in the early years?*

offers a range of useful insights for teachers. She describes how she organised and managed a group of teachers (who worked as mutually supportive colleagues) to consider how inquiry was evidenced in early years education. She adopts the approach of Moyles *et al* (2003) to frame practitioner discussions whilst watching recordings of children playing. Her findings suggest how video-stimulated dialogue can promote pedagogical understanding

of different ways to encourage more investigative learning with young children.

McGregor's paper entitled, *Using drama within a STEM context: Developing inquiry skills and appreciating what it is to be a scientist!* also details a particular pedagogy, designed to promote thinking about science. Her project, though, reports on the creative use of drama strategies, rather than written work, to augment children's understanding about the processes of scientific inquiry within a technological context. Her innovative work using drama places children in role as scientists, so they are encouraged to *work scientifically*. Her findings suggest how the application of dramatic conventions can achieve what Ofsted (2013: pp.10-11) recognises is at its 'highest where pupils were involved in planning, carrying out and evaluating investigations that, in some part, they had suggested themselves'.

McClune discusses *Committing curriculum time to science literacy: the benefits from science-based media resources*. He describes how different pedagogic strategies, used in a creative way to promote literacy skills with Year 6 (age 11) children, can support criticality in reading. His study examines how authentic material, such as text presented in the media, can be adopted and used as a learning resource. His findings corroborate Norris & Phillip's (2003) view that literacy in its fundamental sense is central to scientific literacy, and suggest that the innovative approaches used to engage and guide the children to carefully consider media reports can facilitate them in recognising links between claims and evidence in relation to the trustworthiness of a report.

Articles focusing on assessment in primary classrooms

Earle's paper, *The challenge of balancing key principles in teacher assessment*, clearly and



insightfully articulates the various issues teachers need to consider (and balance) when endeavouring to validate and verify their assessments of children's work. She imaginatively applies a metaphor of a seesaw to illustrate the relationship between validation, that is, ensuring measures of children's attainment are robust and repeatable, with the contrasting issue of verification, ensuring there is substantive and comprehensive evidence that is practicable to assimilate. She also includes in her theorisation concerns about balancing moderation and manageability.

The Serret *et al* paper, *Transforming assessment and teaching practices in science inquiry*, highlights the various forms that professional development can take and describes how teachers might be supported to better understand inquiry in European contexts. The article illustrates rather eloquently how the scrutiny of transcripts from differentiated inquiries (Wenning, 2005), which are subsequently discussed by teachers, can offer insights into classroom practices that augment professional development and further understanding of science teaching and learning processes.

Articles focusing on science leadership

McCullagh & Doherty's paper reporting on *Innovative approaches within Initial Teacher Education to develop emergent science leaders* suggests how a fresh approach to teacher education could address concerns related to the reduced time spent on science in the primary curriculum. They discuss how their 'Student Teachers' College' project, which requires pre-service teachers to demonstrate their competence in four areas: excellence in classroom teaching; peer dissemination; professional development activity with schools and science education agencies; and practice-related research, can facilitate subject leadership skills.

The paper by Mackintosh *et al*, *Developing teachers as leaders of science in primary schools*, considers how the Primary Science Quality Mark (PSQM) award programme can be utilised as a way of addressing the reported decline in the status of science in primary schools. They draw on Fairman and MacKenzie's 'Nine Spheres' (2012) model to suggest the range of leadership skills that are useful for science leaders. Their findings exploring

the impact of PSQM suggest how science leaders' perspectives can be shifted from science learning and practice in isolated classrooms to a whole-school vision.

Bianchi's paper, *A trajectory for the development of teacher leadership in science education*, offers a theoretical model that can be applied to inform CPD. There are five stages of the developmental model, which are described, justified and illustrated through rich descriptive reflections from teachers and teacher educators. The article contributes to the literature on teacher development by considering the various (and often sequential) processes essential for effective CPD.

Scientist-teacher collaboration: exploring the nature of successful STEM placements in primary schools by Choudry *et al* highlights quite unique insights into the processes and outcomes of STEM volunteers working alongside primary science teachers. The reflections of the volunteers on their experiences are provided in much detail, clearly detailing how each reaps greater or lesser rewards. The challenges and benefits of the programme are discussed and reflected upon to suggest how schools might make more effective use of them in future endeavours.

Articles considering transition from primary to secondary science classes

Howard's paper, *Exploring the use of inquiry-based science pedagogies across primary-secondary transition: How does the literature relate this to the declining uptake of science in secondary schools?* considers what the research suggests about the key issues. She highlights that how the subject is taught influences the nature of pupil engagement, subsequent learning and the development of an individual's scientific identity. She suggests that we still need to pay attention to the Rocard report (2007), which identified how inquiry-based science education (IBSE) is still relevant. This is because children like science as they get to carry out experiments and they love investigating, frequently saying, 'You learn loads when you do it yourself, like Science days when you do experiments and don't copy up work' (Hopkins 2008: pp.397–8).

Finally, Coppard's paper, *What does a review of the literature suggest about the teaching of the nature*



and behaviour of matter during the transition years from primary to secondary? critically examines key ideas from the research literature. She discusses what we know from various research studies about the nature and behaviour of matter in Key Stages 2 and 3 (ages 7-14). She offers an argument that suggests the current approach often fails to ensure meaningful learning of the particulate nature of matter and what might be appropriate features of a more successful curriculum model.

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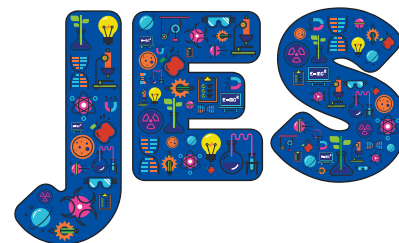
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Professor Deb McGregor, Oxford Brookes University, is the Guest Editor for this edition of JES.

No boundaries, No barriers: the PSTT International Primary Science Conference, Belfast, June 2016



Video Stimulated Reflective Dialogue



● Rebecca Digby

To what extent can Video Stimulated Reflective Dialogue facilitate the development of practitioner¹ critical reflection and understanding of creativity in scientific inquiry in the early years?

Abstract

This doctoral study is situated within the context of professional development, early scientific inquiry and creativity. It focuses on the potential of Video Stimulated Reflective Dialogue (VSRD) (Moyle et al, 2003) as a tool to promote practitioner critical reflection within a community of practice. The study also examines the effectiveness of VSRD in facilitating practitioner understanding of the role of creativity in scientific inquiry in early years education, and the associated pedagogical approaches.

Scientific literacy and creativity are widely recognised as important in children's development and citizenship (Craft, 2002; Harlen, 2008; Worth, 2010). Recent research (Creative Little Scientists, 2014) identifies synergies between science, mathematics and creativity and argues that practitioners should develop pedagogical content knowledge to foster inquiry and creativity in early years science. However, science is not recognised as a discrete subject in the Early Years Foundation Stage (EYFS) (Great Britain, DfE, 2014), and notions of creativity and approaches that foster children's creativity are manifold (Davies, 2011; Kampilis et al, 2009; Sawyer, 2006). This potentially leaves practitioners' conceptions of the role of creativity in scientific inquiry open to multiple interpretations and confusion. By focusing on scientific inquiry, the research aims to provide greater clarity regarding the nature of science within the EYFS (DfE, 2014).

An examination of the role of creativity within scientific inquiry aims to support the development of a shared and meaningful understanding of the

concept. The study also aims to identify pedagogical content knowledge that emerges from engagement in critical reflection within communities of practice.

Twenty-five practitioners from three early years settings are involved in the study, which employs a dialogic methodology (Sullivan, 2012). This paper presents early findings of the study, with a particular focus on the development of shared understandings of creativity in early scientific inquiry and the significance of VSRD in this process. It will also explore the challenges faced by both participants and researcher, for example, promoting literacy with technology and ensuring all voices within a community are captured. Finally, it will consider the impact that VSRD within communities of practice has had on practitioner professional development.

Keywords: Video, creativity, early years, inquiry, professional development

Context

The study is situated within a context that recognises the importance of fostering children's scientific thinking and creative capacities for citizenship (see Craft et al, 2008; Harlen, 2008; Worth, 2010). It examines Video Stimulated Reflective Dialogue (VSRD) (Moyle et al, 2003) as a tool for professional development within communities of practice in early years settings. Focus is placed on the potential of the technique to promote shared thinking and critical reflection on creativity in science inquiry, and the associated pedagogical approaches.

¹ The term 'practitioner' is used to describe any adult working with children within the Early Years Foundation Stage. It includes teachers, early years practitioners and learning support assistants.



The recent publication of a standard for teachers' professional development (DfE, 2016) suggests eagerness by the current government to respond to research that identifies professional development as fragmented and inadequate in meeting teachers' or children's needs (see, for example, Burns & Weatherby, 2014; Darling-Hammond & Richardson, 2009). A focus on improving approaches to professional development bodes well for early years education, a sector acknowledged as suffering from related issues such as low staff qualifications (see Waters & Payler, 2015). However, ensuring that it is equitable, sustainable and transformative is arguably challenging in a culture of standards, identified by Hinchey (2006) as inevitably associated with competency and assessment and, by Hodgkinson and Hodgkinson (2005), as not taking into account the complex processes that teachers draw on as they create new knowledge and develop their practice.

Oberheumer *et al* (2014) argue that recent policy agendas within early years education have resulted in a shift of early experiences from the micro-context of family relationships to the domain of early childhood settings. With this comes an expectation for settings to ensure quality provision for young children to develop cognitive skills in areas of innate learning such as science (Worth, 2010). This puts an implicit focus on establishing environments and promoting interactions that foster creativity, widely agreed to support children's ability to explore and comprehend their world (see, for instance, Barrow, 2010; Craft, 2010; Duffy, 2006). Recent research (Creative Little Scientists, 2014) identifies synergies between science, mathematics and creativity and argues that practitioners should develop pedagogical content knowledge to promote inquiry and creativity in early years science. However, as science is not recognised as a discrete subject in the Early Years Foundation Stage (EYFS) (DfE, 2014), and creativity is widely agreed to be a nebulous concept predominately associated with the Arts (see Davies *et al*, 2004; Kampylis *et al*, 2009; Sawyer, 2006), there is potential for confusion in understanding the nature of creativity in early science inquiry.

Both the possible misperception of the nature of creativity in early science inquiry, and the increasing dominance of competency-based

approaches to professional development, are of concern to this study. Specifically, the study explores the potential of VSRD as a collaborative, inquiry-orientated approach to professional development, as opposed to following a standards-based framework that is potentially reductive in nature. Thus, the study recognises professional development as complex and seeks to make visible multifarious processes, which are at play when practitioners examine and reflect on their understanding of creativity in science inquiry, within communities of practice in early years settings.

Key aims and outcomes

The study aims to:

- challenge the increasing focus on competency-based approaches to professional development and build on successful models, by examining the potential of Video Stimulated Reflective Dialogue (VSRD) (Moyles *et al*, 2003) as a tool to promote practitioner critical reflection within communities of practice;
- explore science inquiry and its associated pedagogical approaches to support greater clarity regarding the nature of science in the EYFS (Great Britain, DfE, 2014); and
- examine the role of creativity within science inquiry to support the development of a shared and meaningful understanding of the concept.

The intended outcomes of this research are thus both clarity of conception of pedagogy for creativity in science inquiry in the EYFS (DfE, 2014) and a tool for supporting practitioner professional development of this understanding in action with the assumption that these must be addressed together.

Research questions

R1: *What are the affordances of Video Stimulated Reflective Dialogue (VSRD) in facilitating critical reflection within communities of practice in the early years?*

R2: *Can VSRD contribute to practitioners' understanding of creativity in early science inquiry, and if so, in what ways?*

R3: *Can VSRD support the development of practitioners' understanding of pedagogical approaches that support creativity in science inquiry and, if so, in what ways?*

Research methodology and methods

The role of talk and dialogic relationships within a community of practice are foregrounded in this study and developed as a framework for interpreting the ways in which practitioners engage with perspectives to collectively construct meaning and new understandings. As such, the study draws on dialogic methodology (Sullivan, 2012) and assumes that multiple, shared perspectives have the potential to spark difference and thus infinite interpretations and meanings (Wegerif, 2014).

The study uses VSRD (Moyle et al, 2003:4) as a research tool and a means for professional development, as it has previously proved to be powerful in *'digging deeper into teachers' knowledge, perceptions, views, beliefs and understanding of a range of pedagogical practices'*. A participative approach underpins both data collection and analysis, and exploratory case study is utilised, as the study seeks to gain understanding of multi-layered social phenomena from different perspectives (Yin, 2009). As such, in each of the case studies, participants collect and select video material of children, and their interactions with children, whilst they are engaged in science inquiries. The contexts for science inquiry are defined by participants and linked to perspectives that have emerged during VSRD sessions. For these sessions, participants come together as a group within their respective community of practice to watch video clips, and all participants are present for the subsequent collective, reflective discussions. All participants share a video clip with the group at least once over the course of VSRD sessions. The role of the researcher is as a 'knowledgeable other' in the field of science in early years education, fully engaged in dialogue during the VSRD sessions. This combination of participant and researcher roles are well suited to the case study approach as, by nature, interactions are action-orientated and thus allow for understanding to be directly interpreted and put to use for professional learning and formative evaluation (Mills et al, 2010).

Participants

Twenty-five teachers, early years practitioners and learning support assistants, and a sample of 50 children aged from two to five years, are involved in the research. They form three case studies,

which have been developed in order to represent some contrasting demographic and geographic features, and to allow for some comparisons to be made through representativeness and reliability (Stake, 2000).

For instance, Case One comprises one team of three teachers and four early years practitioners for 56 children under three who are in both full and part-time attendance at a Nursery and Children's Centre located in an inner city in South West England. Case Two consists of one team of four teachers and four early years practitioners for 84 full and part-time three to four year-olds within a Nursery and Children's Centre in an inner city in South West England. Case Three comes from one Reception class with one teacher, one learning support assistant and up to 30 children; one Nursery class with one teacher, two learning support assistants and up to 30 children; and one Nursery class with one teacher, four learning support assistants and up to 20 children, which support additional learning needs within a primary school in a small town in South West England.

Teachers, early years practitioners and learning support assistants act as a 'key person' (DfE, 2014) to children involved in the study. As such, part of their responsibilities is to offer a secure base from which attachments and settled relationships can be formed, and to ensure that care is tailored to individual needs. Their experience varies from less than one year of teaching to more than 15 years' experience in the field. All but two are female, and their ages range from mid 20s to late 50s, which is representative of the sector.

Ethical considerations

Ethical protocol was framed using the British Educational Research Association Guidelines for Educational Research (2011). Individual participant consent was sought in writing and all practitioners understood their right to withdraw from the research at any time. Assurance was provided on issues surrounding anonymity, confidentiality and safeguarding children when using video data. The researcher collaborated with participants to seek written informed consent from parents for their child to be involved in the study. With respect to children's assent, participants followed ethical guidelines as identified within their respective



settings in order to ensure flexibility to allow children to withdraw from the research setting if they so wished. For instance, an agreed signal between participant and child would indicate that they no longer wanted to participate in a video-recorded session. With the youngest children (under three years), participants drew on their attunement to individual needs to make decisions about whether or not to pursue with filming.

Data collection

There were three distinct phases of data collection in the study. The first phase consisted of hour-long semi-structured, group-focused interviews (Cohen *et al*, 2007), which were filmed to capture participant and community of practice profiles, and to elicit a shared understanding of creativity in science inquiry in the early years, and the associated pedagogical approaches.

During the second phase, individual participants collected four cycles of video data of children engaged in science inquiry. After each data set had been collected, participants identified critical incidents (Harrison & Lee, 2011) for shared analysis in VSRD sessions – hour-long group-reflective sessions stimulated by video clips from up to three participants. Critical incidents were understood as episodes in which there was evidence of children engaged in creative endeavour within the context of science inquiry, as determined by participants. Data were also collected at the end of each VSRD session, through participants' written responses to a summary of emergent themes from initial analysis of the previous session. Each VSRD session was filmed.

The final phase of data collection consisted of a focus group interview and purposively sampled individual interviews that were also filmed. These were carried out to provide further data about the impact that both observing oneself and engaging in the process of VSRD has on practitioners' professional development.

Each setting carried out each of the three phases of data collection at approximately the same time over the course of one academic year.

Data analysis

Data analysis is focused on the group video reflective dialogue sessions and comprises several non-linear stages, which are conducted iteratively with the view that each stage informs the necessity of the next (Charmaz, 2006). Initial and focused analysis during Stage One has been concurrent with data collection phases due to the nature of VSRD (Moyle *et al*, 2003). It has primarily provided insight into practitioners' shared understandings of the nature of creativity in science inquiry, and the associated pedagogical approaches (see emergent themes, which are discussed below).

During Stage One, the first and second phases of data collection were analysed using the qualitative software *Atlas.ti* as a tool for coding. Constructivist Grounded Theory (Charmaz, 2006) informed this process, with particular emphasis put on reciprocity, open interchange of ideas and negotiation between researcher and participant. In practice, initial codes were created by assigning labels to dialogues in VSRD sessions on the nature of creativity in science inquiry and the associated pedagogical approaches. Following this, short memos written by the researcher were used to develop relationships between codes and families of codes. These were then shared with participants as a summary of key emergent themes for discussion.

The summary of emergent themes from focus group interviews and each VSRD session established generalised beliefs, values and suppositions (Cohen *et al*, 2007), and have informed subsequent stages of analysis. Alongside these analyses, insights and developments that have occurred in the researcher's own thinking and learning have been recorded through a reflexive journal. The third phase of data collection will follow this pattern of initial and shared analysis.

Stage One of data analysis also included initial analysis of the first and second phases of data collection, by drawing on the theoretical propositions of Mercer (2000), Mezirow (2000), Korthagan (2010) and Wegerif (2014). This involved use of *Atlas ti* to code evidence of exploratory talk (Littleton & Mercer, 2008) and critical reflection, and it has revealed some evidence of the processes that practitioners engage with within a community of practice to make meaning.

The researcher is presently engaged in Stage Two of analysis, which draws on multimodal transcription (Jewitt, 2012) – a selective and interpretive process of meaning-making for visual data that focuses on patterns of gesture and routines across time and space – to gain further insight into practitioners' approaches to meaning-making. An analytic framework that draws on Wegerif's (2014) perspectives on dialogic space and Barad's (2003) conception of intra-thinking informs this process. During this stage, practitioners will have the opportunity to engage in member checking (Yin, 2009), and a group of expert early years tutors will discuss and feed back on analysis and interpretations.

With respect to the three research questions (see above):

Stage One of data analysis has shown that engagement in VSRD within a community of practice does facilitate critical reflection. In particular, it shows that, as practitioners grapple with a range of others' perspectives on video clips, they can engage in exploratory talk, which can be a catalyst for episodes of critical reflection. Analysis has also revealed that VSRD can contribute to practitioners' understanding of creativity in early science inquiry and the associated pedagogical approaches. This has been particularly evident as practitioners collectively reflect on their interactions with children in the context of science inquiry, mediated through video clips. It has also been evident that VSRD can support the development of shared understandings, which emerge through both cumulative and exploratory talk as well as critical reflection.

Limitations

It is acknowledged that attention will need to be paid to the expansion and generalisation of theories as they are established (Yin, 2009), to address concerns about generalisations that are possible from case studies (Gibbert *et al*, 2008). This will include Stake's (2000) recommendation of sufficient descriptive detail to allow some comparisons to be made through representativeness and relatability to promote ways in which readers may recognise and identify with the case studies.

Early findings and emergent themes

The following summary of tentative themes illustrates significant shared understandings of creativity in early scientific inquiry and its associated pedagogical approaches. They have emerged from Stage One of analysis of practitioners' engagement in VSRD sessions and are drawn across the three case studies:

- **The role of creativity within science inquiry**

In each of the three cases, participants reached the consensus that creativity in science inquiry is defined by the following four broad and inter-related categories: taking risks, being playful, being curious and making links, and innovation. This is in line with findings from the Creative Little Scientists (2014) research project, with the exception of their categorisation of dialogue and collaboration, which was reasoned as not appropriate in some contexts, and scaffolding children's reflection, which was not discussed.

- **Environment and resources**

In each of the three cases, participants reached an agreement that space, both physical and over time, was an important factor in supporting children's immersion in creative endeavour in science inquiry. Participants in all three cases also agreed that open-ended and everyday materials can support children in seeing the unexpected and remarkable, and in exploring difference in order to make meaning. Reflections around this theme resonated with the propositions of Craft *et al* (2012), who identify a link with children finding their own problems to solve and creativity.

- **The role of the adult**

All participants in two of the case studies identified 'being present' (defined as being in the moment, but not always engaging in dialogue or taking a playful role) as supporting practitioners in 'seeing' children's thinking as it shifts, changes and develops through a line of inquiry. This holds some similarity to the well-established phrase in early years pedagogy, 'standing back' (see, for example Cremin *et al*, 2006). However, the term 'being present' places emphasis on practitioners in dynamic and reciprocal relationships with children, as opposed to implying distance from an activity. Although commentary and questioning were suggested as modes for modelling characteristics of creativity, such as curiosity, all participants in all

three case studies recognised attunement as essential to ensuring that talk and questioning scaffolded rather than interrupted children's thinking and immersion in science inquiry. This problematises current non-statutory guidance for practitioners in the early years on questioning (see Development Matters, Early Education, 2012).

● Children's engagement in creativity in science inquiry

In line with Wood and Hall (2011), who suggest that children's curiosity and questions can be expressed through modes such as gestures and actions with materials, in all three cases participants reached the consensus that children often seek a sensory experience, and some a whole body experience, during an inquiry. However, it was recognised that some children do not physically immerse themselves in their inquiries. All practitioners in all cases identified that children can repeat activities multiple times in cycles and from different perspectives when immersed in a science inquiry.

In two case studies, practitioners generally agreed that children can access resources and activities collaboratively, but negotiate their own space and immerse themselves in their own personal line of inquiry. In all three cases, all practitioners suggested that children can have a role in sustaining each other's interests, but that this is not always through dialogue.

The significance of VSRD on professional development

Stage One of analysis of VSRD sessions has identified numerous incidents of exploratory talk and some evidence of critical reflection across the three case studies. For example, during the second VSRD session in Case Study One, participants watched a video clip of four children aged two and three years exploring magnets and 'hoovering' the floor. During the subsequent reflective dialogues, one practitioner begins to critically reflect on her pedagogical interactions with children whilst they were immersed in a science inquiry, and this leads to practitioners engaging in exploratory talk:

M: *'I remember using the magnets, I thought it was important but I realise that I talked so much, I missed what was happening because I was not immersed...'*

I think that I stopped it, I stopped the children from being immersed.'

P: *'Where did that idea come from?'*

[PAUSE]

Y: *'With C it seemed more natural to observe.'*

S: *'Do you think that he (the child) needed you to give him that support?'*

In the first VSRD session with participants in Case Study Two, a practitioner reflects on whether she should impart science subject knowledge during children's engagement in science inquiry. The video clip stimulating this reflection shows an interaction between the participant and one child aged four years whilst he repeatedly fills a container with water and pours it into a stream. In the excerpt from the reflective dialogue below, the participant responds to the exploratory questions from another participant. This leads the participant to pause and question her position before answering:

P: *'I often find myself holding back to allow engagement in the inquiry process. I might know the answer, what they are trying to do...'*

T: *'You're not overly concerned about misconceptions then? You don't want to correct them?'*

[LONG PAUSE]

P: *'I don't think so...I don't think that you need to give them all the information...but, yes there may be a concern.'*

[PAUSE]

P: *'I'm not sure.'*

Exploratory talk, as in evidence above, has frequently been associated with the development of 'interthinking' (Littleton & Mercer, 2008) and meaning-making. An episode of interthinking clearly emerges during the excerpt above, as two participants engage in collective reflection on the role of the adult. This excerpt was the beginning of an ongoing critical reflection for participant P, who went back to consider T's perspective on a number of occasions in the session. As a result of engaging in the VSRD session, participant P both made explicit and began to question her established frames of assumptions.

For Case Study One, this process of collective meaning-making prompted change within the setting. For instance, in response to video clips that had prompted dialogue on the frequency of adult intervention and adult talk in children's science

inquiries, and one video clip in which there was no adult intervention but, instead, a child clearly showing curiosity whilst immersed in a playful line of inquiry, the group adapted their learning environment. A small room was dedicated to children so that they could access a quiet space and provocations to support emergent lines of science inquiry. Significantly, participants wanted to ensure that they were able to 'be fully present' within this space and hear children talk, away from the busy, noisy environment of a nursery. This intention reflected the emergent-shared understanding of pedagogical approaches that foster creativity and immersion in science inquiry. This act has prompted the development of a science policy for the nursery, which has been drafted by participants involved in the case study and members of the senior management team, to reflect shared values and principles for practice informed by VSRD sessions.

All participants in all three of the settings have found the process of VSRD beneficial in supporting the creation of a defined and focused space away from the immediacy of practice. Multiple perspectives, generated and shared by the participants because of the opportunity and the time to observe, reflect and comment on happenings within the video clips, have been identified by participants in two case studies as both challenging and transformative to practice. Practitioners in two case studies have identified that engaging with a 'knowledgeable other' during VSRD sessions has enabled them to 'see the science'. In particular, they have been able to recognise the depth and frequency of children's developing hypotheses; their approaches to pattern-seeking; and their data collection techniques.

Participants in all three case studies have identified a greater awareness of their own pedagogical framing and interactions with children. Individual practitioners in two cases have stated that they have increased confidence in their practice and that they feel more engaged with their established communities of practice. In one case study, the Headteacher has stated that VSRD will be adopted as a model for developing shared understandings of pedagogy within the community of practice of their setting.

Data analysis has so far been focused on participants' dialogues during VSRD sessions, and

how these have contributed to the development of shared understandings. This has provided insight into some of the processes with which participants engage during VSRD. For instance, cumulative and exploratory talk, and collective and critical reflection, have allowed differences in perspectives to be held and challenged within the communities of practices, and they appear to be key factors that contribute to shared understandings on pedagogy and practice. These insights go some way to addressing each of the three research questions. However, in order to fully answer these questions, analysis needs to gain breadth and depth in order to identify the wider range of conditions that contribute to the development of practitioners' understanding of creativity in early science inquiry and the associated pedagogical approaches: for instance, the roles that participants play during episodes of dialogic interaction other than talk, e.g. positive affirmation, active listening, etc. This will be achieved by repeating the coding process on the group video reflective sessions alongside multi-modal transcription.

Challenges faced by participants and researcher

Due to the digital nature of the study and the emphasis on a participative approach, there have been initial issues with practitioners' varying levels of IT literacy. There has also been a need to consider the related concern of immediacy – the extent to which the practitioner focuses on the content of the video rather than the video medium itself – (Bolter & Grusin, 2000). To support development in IT skills, practitioners agreed to practice using video recording devices by taking a number of video clips and to work in experienced and novice pairs where necessary. The issue of immediacy has been, to a certain extent, addressed by practitioners reviewing video material before the VSRD sessions. This has also supported discussion that is critical and content-focused rather than being about the process of using the video.

During VSRD sessions, there has been a need to respect practitioners' differing levels of engagement in dialogue. The related issue of capturing all participants' voices has been overcome through seeking generalised perspectives at the beginning of each VSRD

session, using a simplified Likert scale. Introducing a scale with opportunity for commentary on emergent perspectives has proved a valuable source of data. It is also worth noting that, as practitioners have become more familiar with the process of VSRD in the context of a community of practice, there have been more contributions to the reflective dialogue.

During initial analysis, a key question emerged regarding the trustworthiness of the pedagogical content knowledge that practitioners generate through VSRD. The issue of knowledge trustworthiness within research-in-practice contexts has been asserted by Young (2008), and Winch *et al* (2015) and draws attention to the importance of the external influence of a knowledgeable other or critical friend in the study. In addition to this, published research has been used as a stimulus to challenge existing frames of assumptions during selected VSRD sessions.

Concluding comments

Analysis of the study is still in its early stages and, as such, emergent themes are tentative. However, the themes – the role of the adult and 'being present', and children's collaborative, non-verbal immersion in science inquiry – are of particular interest as they potentially offer new insights into pedagogy that fosters young children's creativity in science inquiry. Additionally, the initial evidence of the impact of VSRD as a professional development tool for practitioners in early years education warrants deeper exploration, to gain further understanding of the processes in which practitioners engage as they develop pedagogical content knowledge within communities of practice.

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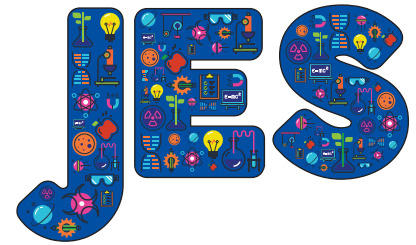


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Using drama within a STEM context: Developing inquiry skills and appreciating what it is to be a scientist



● Deb McGregor

Abstract

This article outlines (and evidences) how process drama can be used in a similar but contrasting way to the well-regarded 'Mantle of The Expert' approach to learning about science. In the Action Research project described here, various process drama techniques were used to purposely place 8 and 9 year-old children in specific types of 'roles' within a particular science context. The activities were designed to relate directly to the Victorian era, when machines were developed to carry out tasks in factories. The context therefore was a time when manufacturing labour-saving devices was burgeoning. In that respect, the activity is related to technology, but the skills required to design, plan, produce and test an original product relate directly to scientific inquiry competencies such as asking questions, generating new ideas and testing them. There is also a requirement to appreciate and understand how the properties of materials available at that time would be more or less appropriate to produce the final fit-for-purpose product. Children's reflections on their participation in the dramatised activities indicate that this pedagogic approach can positively address challenges, which have been noted by Ofsted to deter effective inquiry skill development.

Keywords: pedagogy; drama; inquiry skills; learner identity; working scientifically

Introduction

There are any different ways in which drama can be used to teach science. This can take a variety of forms (miming-movement, freeze-frame, hot-seating, etc.) and mean different things to teachers and children. Children tend to love drama because they 'act out' ideas and 'move' like something (or someone) else, use their 'imagination' and 'get to learn stuff' in a 'fun' way (McGregor, 2012). Ofsted (2008: 10) recognise how it is a less formal way to

learn, that it is 'exciting', 'practical', 'motivating' and even 'refreshing', because the children can 'learn by doing'. These views suggest how, because it is an active and inventive way to learn, it is a dynamic and somewhat spontaneous way to learn.

However, some teachers think of it being used in a more scripted or choreographed way, where a whole class or group 'perform' something (a song, dance or routine of illustrative movements), which is organised and structured by the teacher. In contrast to either totally child-led or teacher-led drama activities, this paper suggests an approach that involves both, with the aim of enabling the children to appreciate what it might be like to be a scientist and to *do* some science.

The primary National Curriculum (DfE, 2014) indicates that the nature, processes and methods of science, which require the application of inquiry skills, need to be developed within varying contexts of science (across the disciplines of biology, chemistry and physics).

The types of investigations prescribed are:

- observing over time;
- pattern-seeking;
- identifying, classifying and grouping;
- comparative and fair testing (controlled investigations); and
- researching using secondary sources.

It is suggested that, through these kinds of experimental approaches that require children to 'work scientifically' (DfE, 2014), they are then equipped with the scientific knowledge (and skills) to understand the uses and implications of science, today and for the future.

Through 'working scientifically', the programme of study in the National Curriculum identifies the inquiry skills that older primary children should



nurture to grasp the nature, processes and methods of science, including:

- asking relevant questions and using different types of scientific enquiries to answer them;
- making systematic and careful observations and, where appropriate, taking accurate measurements...using a range of equipment;
- gathering, recording, classifying and presenting data in a variety of ways to help in answering questions;
- recording findings using simple language, drawings and labelled diagrams;
- reporting on findings from enquiries, including oral and written explanations or presentations of results and conclusions;
- using results to draw simple conclusions, make predictions for new values, suggest improvements and raise further questions; and
- using straightforward scientific evidence to answer questions or to support findings.

Pedagogically, Harlen (2014) identifies how the development of the kinds of inquiry skills outlined above with primary pupils presents a range of challenges for teachers. Inquiry, however, extends well beyond just 'practical work' or 'hands-on' experiences and is not just concerned with children 'discovering' for themselves, but is concerned with the development of a range of skills.

The particular skills that Harlen (2014) highlights include:

- raising questions, predicting and planning investigations;
- gathering evidence by observing and using information sources;
- analysing, interpreting and explaining; and
- communicating, arguing, reflecting and evaluating.

Ofsted (2016) recognises that these types of skills, including pupils evaluating and drawing conclusions from their science work, are limited and that this is underpinned by teachers' lack of expertise. The use of process drama to develop these skills, however, can be developed within a Dramatic Inquiry (DI). The extent to which this is possible is discussed in this article.

The Royal Society (2010: p.66), also concerned with the way in which children are prepared scientifically

for the future, describe how understanding science involves much more than just the learning of facts. They highlight the importance of the development of scientific and research skills within science education, to serve two key objectives:

- to increase the scientific literacy; and
- to stretch and challenge those with the potential to become tomorrow's scientists.

This is echoed by the Confederation of British Industry (CBI) in their 2015 report, which emphasises how learning science must be addressed at the primary phase of education if schools are to nurture scientifically literate citizens for the future.

Drawing together, then, the intent of the National Curriculum (2014) to equip learners with the ability to work scientifically; Harlen's (2014) recognition that development of such skills is challenging for teachers; the concern of both the Royal Society (2010) and the CBI (2015) regarding the scientific literacy of future generations, and the evidence from Ofsted (2016) that suggests key inquiry skills such as evaluating and concluding are limited in many primary schools, the approach described here, using drama to teach scientific inquiry skills and literacy, is suggested as a way forward.

Adopting the pedagogy described in this article can enable teachers to appreciate how to support and nurture the development of a range of inquiry skills in primary science contexts. As Ofsted (2013: pp.10-11) have recognised through their regular inspections of primary and secondary schools, *'achievement is the highest where pupils were involved in planning, carrying out and evaluating investigations that, in some part, they had suggested themselves'*. This is supported by evidence that inquiry skill development was limited when *'pupils were not making decisions ...'* about what to investigate or how to do something. They elaborated that, if children were only invited to *'Guess what you think will happen'*, rather than predict and explain their reasons or hypothesise (that is, suggest why they think a particular thing will happen), then development of effective inquiries was limited. They also found that contextualising the classroom activities, so that the children were able to appreciate how an inquiry might relate to their everyday lives, was more

beneficial, because they found that youngsters '*learnt best when they could see how the science they were studying linked to real world experiences*' (Ofsted, 2013: p.10).

This paper suggests, then, that a teaching (or pedagogic) approach that integrates process drama with the opportunity for children to engage in a scientific inquiry, set within a technological context, can facilitate development of investigational skills. In this way, the children are able to experience 'working scientifically' through being-in-role in a sequence of different, but related, dramatised activities. They are supported in asking their own questions, and generating and testing their own possible solutions to scientific and technological problems. The adoption of the 'roles' offered to the children, in a progressive sequence, enables them to consider at length (and in depth) the contextual situations within which a scientist or technologist might have worked in a Victorian factory. Providing such a rich and immersive experience offers them many opportunities to practice and apply scientific skills (like a scientist) to solve a technological conundrum.

Therefore, the research question posed, and addressed, in this paper is: *How can different forms of drama support the development of inquiry skills in an historical and technological context?*

The historical and technological context for the drama activity was drawn from the story about the work of Mattie Knight (1838–1914). She lived in North America and became an inventor, through applying her careful and detailed observations of the ways in which things worked. She had already crafted sleds and kites for the local townsfolk. However, after a visit to a cotton mill in New Hampshire where her older brothers oversaw production, she witnessed a flying shuttle seriously injure a young boy. This was reputedly the stimulus for her to invent a safety mechanism that meant that that type of incident (where a piece of a mechanism was loose and became a safety risk) would not happen again.

The research approach

The use of process drama within the teaching of science can be used in a variety of ways, as suggested at the beginning of this paper. However,

in the study reported here, it was intended that the project should be a co-operative inquiry; that is, the class of Year 5 (age 10) children and two teachers (one a scientist, the other a drama specialist) worked together in an interactive way to each other's mutual advantage. They learned from and with each other. In process drama, engagement learning activities can result in dynamic and sometimes quite spontaneous responses from the children to the guidance and/or instructions given by the teachers. In this case, in the final part of the lesson, the children were presented with the challenge of designing, producing and testing a bag that could carry different objects, using only materials available in Victorian times. The teachers were introduced to incredible innovative and unique solutions that the children collaboratively constructed. From the children's perspective, they learned a number of things about Mattie Knight and her work, how to translate a design into a real thing that was 'fit for purpose', and how to be scientific in the way in which they solved a technological problem. The process drama in the activities (constituting a two-hour lesson) reported on here consisted of a series of related tasks. With this kind of approach, the epistemological understandings (regarding Mattie Knight's work and the nature of producing something that required scientific skills) of both children and teachers were extended (Heron & Reason, 2008).

The lesson gradually shifted from initially being teacher-led to ultimately providing much more scope for the children to be agentive in the way they worked-as-a-scientist in role. The intention, through this exploratory action research approach, was to investigate how drama might influence the development of inquiry skills in a Year 5 primary school classroom. It was hoped that the children, co-operating with the collaborating science and drama teachers, would extend their understanding of the historical influences on science and technology and develop an appreciation not only of Mattie Knight's work, but also the nature and processes involved in scientific and technological endeavours.

The school involved is located on the outskirts of Oxford, and is Ofsted-rated 'Good'. There are just over 300 pupils enrolled in this co-educational school, which has an intake from 4-11 years of age.



There is a majority of white British heritage pupils, with some ethnic minority children, mostly from Asian backgrounds. The teachers involved in teaching the intervention (as part of the action research approach) were also the researchers. A variety of mixed methods were used to assess how the children responded to the various roles with which they engaged during the drama inquiry. The data collection methods included classroom observations that focused on interaction and talk, which were collated through photographs and field notes; post-intervention questionnaires given to all the children who participated and a reflective focus group discussion that involved 3 boys and 3 girls

with a range of abilities. The quotations from the children, both during and after the activities, were analysed to explore their views of their developing prowess as technologists solving a problem and, in so doing, using inquiry skills to plan, proceed and evaluate as scientists.

The approach to using process drama in the action research

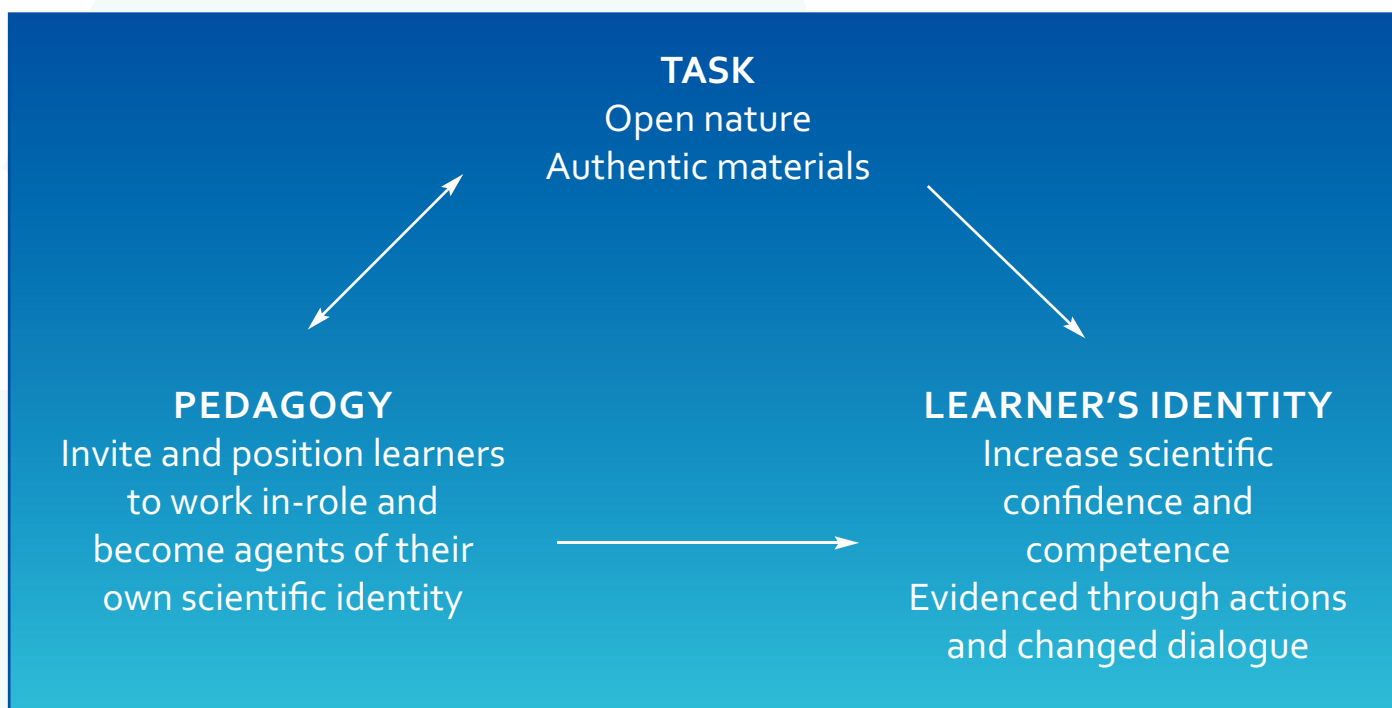
The use of drama as an interventional approach has been developed by Dorothy Heathcote (1985) and is widely recognised as an approach to develop the *Mantle of the Expert (MoTE)* in an inquiry situation.

Contrast of the *Mantle of the Expert (MoTE)* with the process drama approach, a Dramatic Inquiry (DI)

	Mantle of the Expert (Heathcote, 1985)	Process drama approach (McGregor, 2014) within a STEM context
Contextual use	Originated in the Arts (English & drama)	Originated in science to support <i>Working Scientifically</i> (DfE, 2014) and extend development of inquiry skills
Timescale	Extended over several weeks Several classroom episodes	A lesson of 2 hours
Approach	Provide 'as if' (p.61 in Swanson, 2015) opportunities.	To develop a gradually immersive experience with the finale of being 'a scientist in role'
Position	Provide 'to pretend to be' opportunities...in various roles... Progressive, from company employee to expert scientist	Includes a range of positions (see Table 2), developing from being a machine, an expert technologist, member of patent committee Immersive
Extent of authenticity Roles Materials Task	Working-in-role as someone involved in the 'Inquiry' Individuals retain a role Artefacts (documents, reports, photographs, etc.) An inquiry to explore something	Working-in-role with others as a team of scientists Collaborating mini-communities of inquiring scientists Late 19 th Century resources Design an original carrier (bag)
Analysis of impact	Reflectively considering dialogic development and (various) outcomes at end of inquiry	Post-intervention questionnaire Dialogue analysis Group interviews with learners Artefacts produced as an outcome of the task

Table 1: An illustration of key differences in the *Mantle of the Expert (MoTE)* approach and the Dramatic Inquiry (DI).

Figure 1: A diagram indicating how the teaching (pedagogic approach adopted) that involved a particular kind of open task, using authentic materials, would support development of the children's identities as more capable scientists.



She explains how this approach enables students to 'see' themselves as they demonstrate others' ways of being and working. She also indicates how visibility of ideas can offer possibilities for improvement. She highlights how the inquiry tasks can offer a 'realistic' experience and that students will *feel* that they are behaving with authenticity. This STEM inquiry has been developed with Heathcote's (1985) *MoTE* in mind. However, the process drama approach to science used in this project has been designed to allow teachers to easily adopt it. There are some similarities and differences (see Table 1) in the two approaches. The whole (DI) activity can be implemented in two hours. In trialling the materials and approach, an afternoon in the school day was utilised for the Mattie Knight inquiry.

The theoretical model underpinning the way the intervention was developed

The action research approach assumed the use of authentic Victorian materials (see Figure 2 below) and a task within the DI that was open-ended, that is, there was not a single solution anticipated and the children could produce a wide range of different responses. It was essential in the intervention that children were invited to work-in-role as a sequence of immersive activities. The

pedagogic steps in the DI are summarised in Table 2 (below). The authentic materials used in the activity for the design task were: sacking or hessian, brown paper, gummed paper (with a damp sponge in an old tin to wet it), string, scissors, needle, thread, assorted buttons and brass split pins. It was anticipated that the children would be agentive and develop their skills and understanding of being a scientist in the successive positions in which they were placed, and the associated roles they undertook. It was hoped that their confidence and competence would increase as they worked collaboratively with others in their class on the various dramatised activities.

How did the teacher develop the Dramatic Inquiry (DI) (the pedagogic approach) to 'position' the learners?

To help the children engage in the DI as scientists, it was important that they quickly became immersed in the Victorian factory context in which Mattie Knight worked. To help 'set the scene' and provide a purpose for designing an original bag, there were successive activities framed to help them appreciate why an original bag design was needed. The children were engaged in participating in-role in a variety of ways, as summarised in Table 2:

Table 2: A summary of the teacher’s pedagogic approaches that were intended to place the children in particular kinds of positions to think, learn and be a scientist-in-role in Victorian times.

Teacher Approach to develop the DI	Position of learners
Inviting the children to imagine the doorway into a big Victorian factory building. Subsequently sharing pictures of Victorian factory machines involved in manufacturing paper bags. Children were asked to work in groups and ‘move’ as a working machine	As a virtual visitor to a late 19 th Century (Victorian) factory
Inviting the children who would help carry shopping in a cone-shaped bag to consider the issues for packing heavy and light things, carrying soft fruit or eggs all the way home and then placing the bag on a counter top ready for unpacking	Technologist thinking about issues and possible (re)design of the cone-shaped bag used at the time
Inviting the children to work together to design, make and test a bag to carry a particular object, or several things	Collaborating technologists and scientists inventing (designing and making) an original object (a bag) to solve a ‘real’ problem
Inviting the children to create a written document (poster) that describes what their original design is and how it would work. They have to explain how it is original, justify their use of particular materials for different parts of the bag, and demonstrate how it is ‘fit for purpose’	A technological and scientific team presenting and explaining how their invention works, what is original about it and justifying how it is ‘fit-for-purpose’
Inviting the children to listen to presentations from each group developing an original bag and then judging the originality and functionality, before agreeing to award a ‘patent’ certificate	A patent committee member judging the originality, functionality and explanation of a group’s invention



Figure 2: Illustrations of some of the authentic materials used by the children.

Data gathering

Various forms of data were gathered via reflective questionnaires that the children completed. The particular focus of the questions sought to ascertain the children's self-reports on their views of the ways that the drama activities had promoted:

- asking questions;
- thinking of new ideas;
- testing ideas;
- explaining things;
- observing how things change;
- comparing things;
- seeing patterns;
- using evidence to make conclusions;
- using scientific words;
- making decisions like a scientist;
- thinking like a scientist;
- acting like a scientist; and
- being a scientist.

There were also focus group discussions after the lesson, supplemented by audio-recordings of the lesson taught and the teachers' reflective field notes.

Findings

The children's responses were collated, sorted and then ordered, applying principles that Creswell and Plano Clark (2007) offer to 'transform' data in order to look at it in different ways. The utterances during and after the lesson were also transcribed to enable a thematic analysis (Corbin & Strauss, 2015). The transcriptions of the lesson and the focus group discussion were analysed with two key theories in mind: Urrieta's (2007) notion of figured worlds to consider how the children negotiated and performed their identities (as well as acknowledging others and artefacts) within the Victorian context of designing and making a bag; and Wenger's (2001) view of narratives of self, applied to explore how the participating children might conceive their learning trajectories within the series of drama activities.

The analysis of the questionnaires (see Table 3) suggested that *all* the children thought the DI supported them in 'asking questions', 'thinking of new ideas' and 'using scientific words'.

Table 3: Collated responses garnered through the questionnaires, from the class of children (n=22), to indicate which inquiry skills they thought they developed through the DI.

	% Children's responses after the intervention lesson
Asking questions	100
Thinking of new ideas	100
Using scientific words	100
Testing ideas	96

This view was exemplified by one boy who said confidently at the end of the lesson, '*Normal science lessons – mixing and solving stuff...but this you were using your imagination as well and creativity which I really like*'.

	% Children's responses after the intervention lesson
Thinking like a scientist	96
Acting like a scientist	96
Being a scientist	96
Making decisions like a scientist	86

Table 4: Collated responses garnered through the questionnaires, from the class of children (n=22), to indicate how far they thought they were behaving and thinking like a scientist through the DI.

Interestingly, when the children were asked to consider how much the DI helped them 'think', 'act', 'make decisions like a scientist' and feel like they were *being* a scientist, the vast majority of the class (see Table 4) thought they did a great deal. To exemplify this, one girl stated that:

'you could see the reason behind why we were making bags and we were using the materials that they had back in that time'; another said, 'it got your mind thinking about how you can use things from that era'. One boy added that he felt they were 'grappling with stuff from Mattie Knight's time'. The way that using authentic materials really helped them think more deeply was suggested by one girl, who explained that 'it made me feel like Mattie because we were using all the materials from her time and you couldn't just use what you wanted'. They felt that they had to think 'more', 'imagine and...paint a picture in your head' and that demanded much more concentration, because 'you put yourself in another person's shoes'.

When questioned further about what they enjoyed about working-in-role as a scientist?

Children indicated that they enjoyed themselves more than usual because there was more likelihood of unplanned happenings in the lesson and it wasn't the normal *listen, do and write up what we did* kind of lesson. Their responses suggested that it was enjoyable because, as one boy explained, 'you know something fun is going to happen'. Asked about how they felt when in role, they explained it made them feel 'excited', that they were in 'a whole different world with a team of scientists' and that everyone in the class 'was a scientist'. One of the older girls, whose parents were both scientists, highlighted how many of them appeared to feel, saying, 'it made me want to be a scientist'. The opportunity to act and think in role as a scientist really seemed to inspire them! Their learning trajectories, it seemed, shifted beyond just achieving in the classroom, with some stating that they understood what it was to 'be a scientist' and even 'wished' to be one...and thought they 'could be as scientist one day'.

Conclusions

Although this was only a small-scale study with one Year 4 class (of 8-9 year-olds), the objective – to explore whether the use of dramatic inquiry could 'shift' children's identities from thinking that science was too hard and difficult to considering how they might succeed in science, and even wish to 'become' a scientist – appeared to have been achieved.

There was evidence that various inquiry skills were developed, as well as the children developing their identities as scientists. This project, therefore, suggests that teachers can 'set up' learning experiences (using appropriate tasks and authentic materials) to support children believing that they *do* science and could even *become* a scientist one day. As Brock *et al* (2006) suggest, we should not consider identity as a fixed entity, but rather one that is fluid and dynamic and that can be shaped and influenced by inspirational activities in classroom settings.

This project, by developing a dramatised scientific inquiry that positioned learners differently at successive points in the lesson, not only illuminated for the children different dimensions of scientific understanding, but also extended their appreciation of what it was to think, act and be scientific. By using drama, there appears to be a huge potential to also enrich children's scientific literacy, so that they are no longer turned off science, but are excited and motivated by it. It appears that they feel they can apply and understand a vocabulary-heavy subject and their personal curiosity can be fulfilled to some extent. They certainly demonstrated how they were able to develop investigative, questioning and thinking skills to a noticeable extent, not only for themselves, but also so that their teachers could recognise this in their 'roles' as scientists.

It appears, then, that a Dramatic Inquiry (DI), pedagogically set up in the way that is outlined in this article, can:

- Extend children's experiences of and engagement with inquiry skills;
- Hone children's questioning and thinking skills;
- Promote a phenomenological empathy with someone (from history) doing scientific work;
- Enhance children's appreciation of the ways in which science is relevant and useful to everyday life;
- Enable children to more strongly identify with *being* a scientist;
- Illustrate the impact of an innovative curricular approach on the development of children's scientific and learning identity;
- Promote an individual's identity in various ways as a scientist, from just 'thinking like', to believing that they are 'being like', a scientist;

- Show that working collaboratively with others, on an authentic task, can enhance the range of inquiry skills developed; and
- Show that the children re-constructed different aspects of themselves (as a technologist and scientist) and gained different perspectives when placed in new and different situations as learners ‘...because they are afforded’ (Holland *et al*, 1998) different perspectives through engagement in the strongly contextualised tasks.

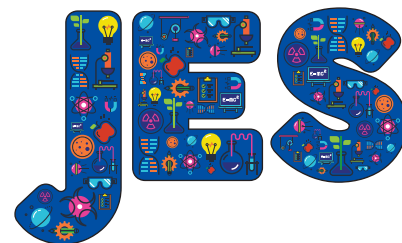
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Committing curriculum time to science literacy: the benefits from science-based media resources



● Billy McClune

Abstract

Science reported in the media is authentic source material to stimulate interest in science research and innovation, to learn how science works and to consolidate science literacy skills and subject knowledge. Media reports, intended to communicate science research and innovation, provide opportunities for teachers to develop among their pupils the critical reading skills that are essential for promoting literacy in science.

This study focuses on a curricular intervention with upper primary pupils (age 11 years) and uses science reported in the media to facilitate the development of critical reading. It investigates the use of media-based resources and teaching approaches that systematically address the critical reading at a foundational level. It reports on classroom observation and pupils' behaviour in relation to dialogue that supports negotiation and clarification, as pupils experience opportunities within the curriculum to revisit, consolidate and develop their critical reading skills.

Keywords: Science literacy; critical reading; media-presented science; school science teaching

Introduction

Science-based media reports are part of the fabric of young people's media-driven science experience. They do not have to systematically tune in to news broadcasts to be aware of science-based issues relating to environment, climate and health. These are reported, shared and talked about alongside space science, gene therapy, and the latest applications of Nanotechnology. News is pervasive and pupils can know about and be motivated as much by the challenge to produce clean water and boost crop yield in the developing world as by innovations in 'smart' materials built into their mobile phone, or the prosthetic appliances for Paralympic athletes.

However, awareness of science-based issues provokes a response in each of us. It may be the distrust that emerges from unfamiliarity, curiosity that is fuelled by confidence and growing understanding, or the engagement that is stimulated by a sense of ownership and citizen responsibility. The critical nature of the individual and community response that we make to these media-driven experiences will be influenced by the nature and degree of 'science literacy' that the experience of school science has engendered. Encounters with science-based news are inevitable and science education can have a role to play in equipping young people to engage critically with the concerns of today and the yet-to-be-discovered science-related issues that will affect us tomorrow.

'Science literacy' is multi-dimensional and includes the capability to read and respond critically to news reports with a science component (Millar & Osborne, 1998). In the context of science-based media reporting, it is demonstrated, at least in part, in the ability to evaluate the validity and reliability of scientific claims, methods or designs that are reported. In addition, it can be seen in the reader's awareness of, and response to, media-driven constraints that influence the language and substance of media reports with a science component.

Newswise is a media science project, which was the basis of this study. It proposed a three-phase curricular intervention based on reading news with a science component. Teachers' commitment to the programme involved the use of a media source as stimulus material. The media source news report about micro-needles dictated the content area and required them to commit curriculum time to an interdisciplinary project under the theme 'science in the world around us'.

The programme was original in its emphasis on an interdisciplinary approach to media literacy and



science with primary age pupils, and the integration of strategies not commonly used in the same curricular areas or in conjunction with one another. These strategies were based on critical reading and response tasks described elsewhere (Jarman & McClune, 2011; McClune & Alexander, 2015).

This paper reports on one of three parts (the foundational reading task) of an exploratory science programme to promote reading science news with upper primary pupils (age 11 years) in the UK. The intervention included foundational, intermediate and higher-level tasks to promote critical reading of science-based news reports. The foundation level activity contains two reading and comprehension tasks, which are specifically tuned to news media. They require pupils to carefully examine the news text. News is a unique genre, with characteristics that differ from much of the textbook material that primary pupils experience in school. Two foundation tasks – 'News Bug' and 'Sketch-pad' – structure critical reading in a media context. Pupils completing these foundation tasks should be able to:

- Use 'key questions' to examine a science news report;
- Decide if a science news report can stand up to scrutiny; and
- Make a graphic to supplement a science news report.

Figure 1 illustrates the end point of one activity, where the model and supporting documentation are indicators of pupils' engagement with the task.

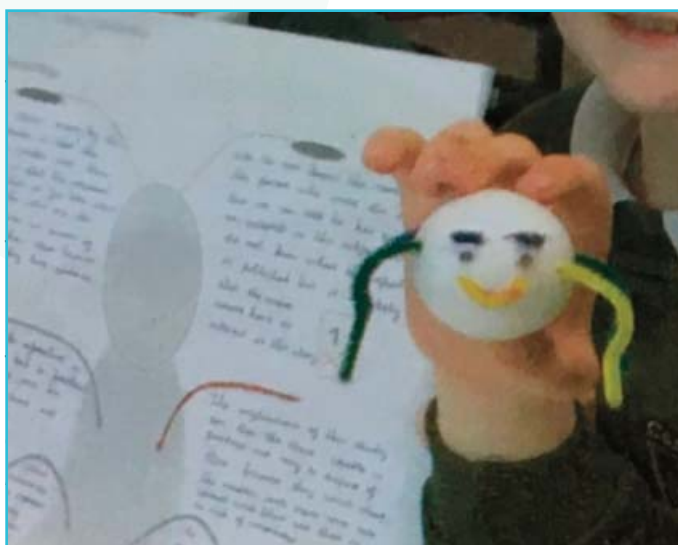


Figure 1: The News Bug completed.

Development

A number of theoretical constructs underpin current thinking and practice in relation to the inclusion of science-based media reports as an element of the school science curriculum. These include the ideas that:

- Science literacy should equip young people to engage with science in the world beyond the classroom. As such, it is considered an important goal of a science education;
- Science reported in the media has unique and challenging characteristics and requires particular attention in the science classroom;
- The learning intentions and pedagogies associated with effective use of media-reported science have implications for interdisciplinary approaches to teaching; and
- The development of a pupil's capability for critical reading of science-based media reports is an essential skill in the development of science literacy.

In their review of literature relating to science in the media, McClune and Jarman (2012) explored more fully the links between these perspectives. A number of key ideas are summarised below.

The concept of science literacy is contested. It has multiple definitions and may be interpreted differently, depending on the audience and the context in which it is discussed. Yore (2012) describes visions of science literacy. Historically, science education focused on the preparation of a scientific elite or a well-educated workforce. It was located around recall and use of established and uncontested knowledge – textbook science. While this view of science education is still evident, it is now common to see science literacy defined more widely to include, among other things, the capability to handle with confidence science encountered in the world beyond the classroom, i.e. the science that is woven into the fabric of everyday life; the science of home and work, of leisure and entertainment. Consequently, one acknowledged goal of science education is that pupils should be able to read and respond critically to media reports with a science component. This idea is expressed consistently in policy documents and curricular discussion papers that have influenced the development of science education in recent years (Millar & Osborne, 1998; Millar, 2006; National Research Council, 2012). It can be argued

that, in promoting science literacy, science educators are endorsing the role of science in equipping individuals and communities to engage with significant cutting-edge and sometimes contested science-based issues that have local, national and global impact.

News, including science-based news reports, come in many formats. Newsprint competes with television and radio broadcasts. More recently, these traditional sources have been supplemented or overtaken by a host of Internet sources, from commercial websites to news Apps. Increasingly, news is distributed by celebrity 'Tweets' and by individuals through shared links with 'Facebook friends' or in the form of *YouTube* and other platforms.

Newsworthiness is a common element linking this abundance of science news sources. In all of these, 'News Values' underpin the science reporting. Jarman and McClune (2007), in addressing the role of news media in the development of scientific literacy, point out that science is often newsworthy, i.e. it is characterised by well-defined news values, so it satisfies the needs of the journalist who is looking for a story. Science is interesting and sometimes entertaining, so it meets the programme-scheduling guidelines followed by directors and producers working in the broadcast media. Science news often relies on a 'WOW' factor, the capacity of science to surprise and amaze.

Within these categories of newsworthiness and entertainment, the science component of the report may be dominant or recessive, i.e. it may be the main focus of the report or simply a supporting element underpinning the story, linking it to one or more big ideas in science. The focus is often on science research and technological innovation. In addition to news values, it must be acknowledged that these sources of news also have their own agenda, sometimes clearly evident in the reporting style, but often presented more subtly.

Media-based science presents teachers with new opportunities and new pedagogical challenges.

The 'textbook science experience' and the 'media-driven science experience' differ in a number of respects:

- School science and media science differ in their setting – media science is free choice, unplanned, unstructured. We meet it in informal settings and we choose it. In contrast, school science is structured, planned, often assessed. We meet it in formal settings and it is imposed, rather than selected.
- School science and media science differ in their purpose – media science is intended to entertain and to inform. It can be profit-making. School science is intended to build knowledge, develop skills and promote learning.
- School science and media science differ in their content – media science is cutting-edge and sometimes contested, speculative and uncertain. School science is factual, established, generally agreed textbook science.

To some, school and media-driven science may appear to be incongruous, even incompatible, while others would view them as complementary. There are acknowledged limitations when science is reported as news. While it is important that teachers acknowledge different viewpoints, the opportunities, particularly for interdisciplinary learning, are an important benefit (McClune, Alexander & Jarman, 2012).

As a consequence of these differences, school science and media science invoke different responses from the learner to basic questions: Why am I doing this? What is in it for me? Is it important to my family, my community, and me? There are questions also for the teacher. When compared to school science, media science has a greater element of pupil choice, pupil ownership and relevance. Hence media stimulates the contextualisation of science, highlighting its relevance to the world beyond the classroom.

Consequently, media sources give access to some learning goals and anticipated outcomes that include the ability to:

- Read opinion-text thoughtfully, identifying and assessing the impact of limiting clauses and persuasive language;
- Explore factual-text to assess its accuracy and reliability and substance;
- Read purposively, seeking to identify claims and evaluate links between claim and evidence; and
- Read and respond critically to news with the science component.

These outcomes are more likely to be associated with the development of literacy than with science education. They do however represent a transition between science literacy and what has been described as literacy in the fundamental sense (Norris & Phillips, 2003).

While science-based media sources can be used to promote and consolidate science learning alongside a range of literacy skills, the development of critical reading skills is a primary objective. The basic concept and the developmental stages of critical reading are well described elsewhere (OECD, 2006). In applying these ideas in the context of this study, they have been refined and are described as a series of levels that are increasingly challenging for the reader (see Figure 2).

The framework of strategies and resources used in the study is based on a model of critical engagement developed for science in the media. That model identified science knowledge, literacy skills, media awareness and aspects of critical thinking (discerning habits of mind), which were necessary elements in making a critical response to science-based news. A subsequent framework of learning intentions, described at foundational, intermediate and higher levels based on this model, was developed (McClune & Jarman, 2010; 2011).

Methods

This empirical study focuses on news text and on activities intended to promote aspects of critical reading. Classroom practice was scrutinised in order to gauge the influence of teaching approaches and the subsequent learning opportunities on pupils' ability to critically examine a media report with a science component. The teacher's lesson management skills, subject knowledge, confidence and the tone of teacher-pupil relationships all had an influence on the classroom atmosphere and the learning environment. However, the teachers' approach to their role as facilitator or controller was most significant. Approaches that were characterised by questioning and discussion that was pupil-led were well suited to the news-based critical reading activities.

This study was based on classroom observation and aimed to shed light on elements of classroom practice, in particular pupils' behaviour in situations that supported dialogue and questioning. It was a qualitative study, observing activities that signal pupils' conceptual understanding when engaging with activities based around a news report about a groundbreaking medical development. Researchers looked for pupils' appropriate reference to media sources when negotiating the outcomes of the tasks. A variety of types of data

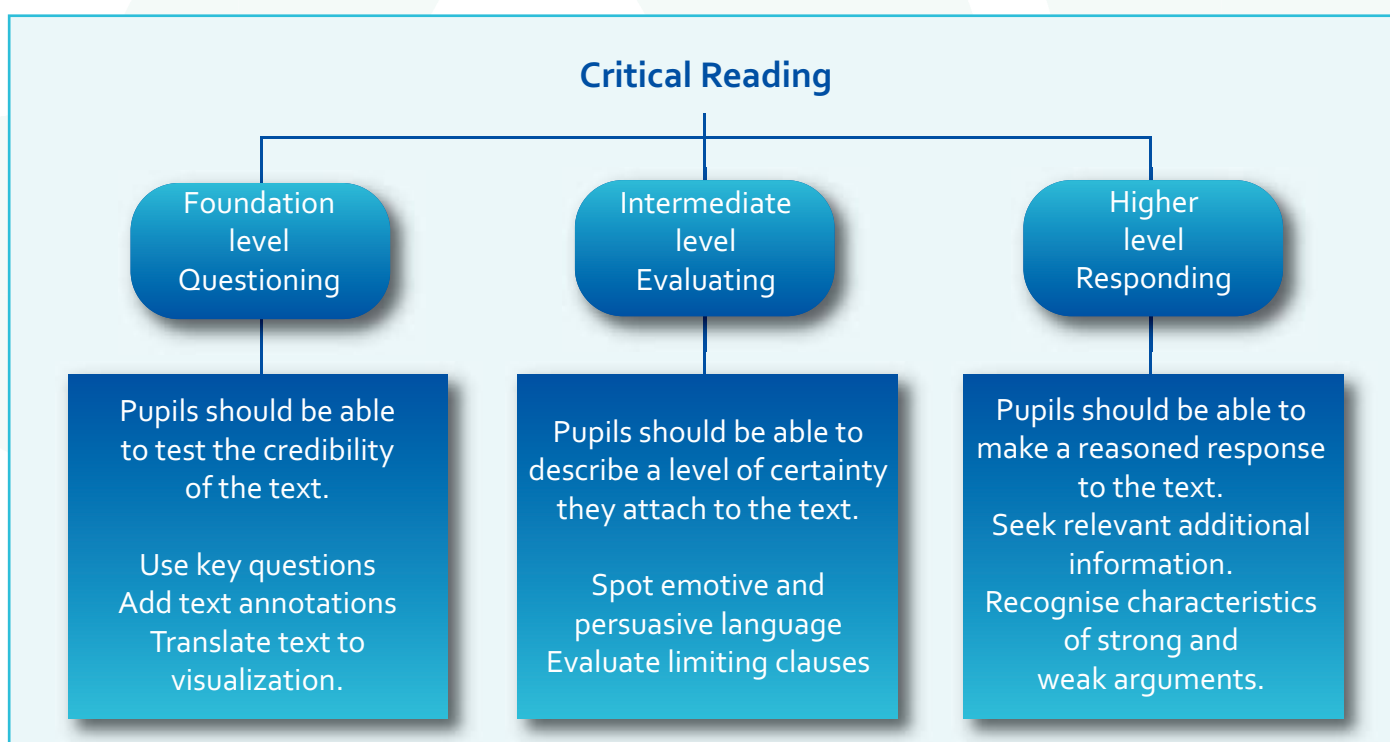


Figure 2: A model for levels of critical reading

was collected, including examples of writing, drawing and modelling completed by pupils individually and in groups. Pupils made audio-visual recordings of their group tasks and discussions. The aim of this pupil-controlled approach to data collection was to minimise any disruption to the group dynamic or distraction due to an unfamiliar adult 'listening in' to the group. Pupils usually passed the camera around to ensure that all participants were recorded. The study also draws on observational records from researchers who spent time in the classroom. Audio-visual recordings intended only to supplement or confirm researchers' field notes were not transcribed. Data were also collected from pupils using questionnaires and semi-structured interviews. Analysis of the outcomes of two core tasks relating to different elements of critical reading at a foundational level, which provided the most substantive evidence of pupils' engagement with the tasks, will be reported here.

Core activities

The two core activities focused on accessing and extracting information – 'building a News Bug' (see Appendix 1), and on translating information extracted from the text for the purpose of communication, using a 'Sketch-pad' (see Appendix 2), to make a visual representation based on the text. Researchers used teachers of science and English as experienced readers to provide a benchmark standard for these critical reading tasks.

In the first core task, 'build a News Bug', pupils demonstrated their ability to assess the value of the report as a reliable source of science-based reporting. Pupils working in their usual class groups, assigned by the class teacher, used information from the text to construct a three-dimensional representation of a news report (a 'News Bug') and used this to determine the robustness and stability of the news report under scrutiny. Critical reading in this context involves assessing the text against 6 key questions and deciding if it reaches what they consider to be a satisfactory standard for a comprehensive and credible news source. Each question is linked to a 'leg' of the News Bug. For each question area in turn, the readers add a leg to the bug if they consider that the text stands up to scrutiny in that

area. The model bug produced by the group represents their analysis of one text. A bug with only a few legs indicates a news text that does not stand up to scrutiny. The group's News Bug and the insights that they demonstrate in justifying their assessment of the text in key areas are indicators of their critical reading capability at a foundational level (see Figure 2).

In the second core task, 'Sketch-pad', pupils demonstrated their ability to access core science ideas underpinning the text by translating from written text to visual representations and explaining these to a peer group.

The News Bug activity

This focuses on three aspects of science-based news reporting to which a critical reader should pay attention. These are, firstly, the structure of the report; secondly, the plausibility of the report; and, finally, the reliability of the science component of the text. Table 1 illustrates how these aspects are explored in 6 key areas of the text: context, substance, language, science sources, methods and conclusions.

Pupils assessed the news report, *More needles means less pain*, using the News Bug activity. The source of the report was indicated to be the *Daily News* and the byline was attributed to 'a special correspondent'.

The opening paragraph stated that: '*For many people the thought of an injection brings back unpleasant memories of a visit to the doctor. That could all change. Researchers working at Queen's University Belfast hope to have a painless injection. They aim to replace a single needle with hundreds of tiny "micro-needles" made from the same material used in soft contact lenses*'.

A pupil reading critically and applying the key questions in relation to the structure of the text might conclude that there was insufficient information about the credentials of either the media source or the journalist. The substance of the news report – the possibility of pain-free injections – is likely to be a topic of interest and relevance to most people.

The article also reports that: '*They [micro-needles] have been described as feeling like Velcro on the skin*'.

Table 1: Characteristics of a comprehensive science-based news report

Aspects of a news report	Focus of the News Bug questions	A comprehensive news report should be:
Structure	1. Context	From traceable and reliable media source.
	2. Substance	Important and have meaningful consequences - A report that has impact.
Plausibility	3. Use of language	Balanced –Having measured use of fact and opinion, emotive and persuasive language.
	4. Science sources	Relying on identified, traceable and reliable science sources.
Reliability	5. Methods	Providing information about the research approach and methods.
	6. Conclusions	Presenting conclusions that relate to claims and evidence.

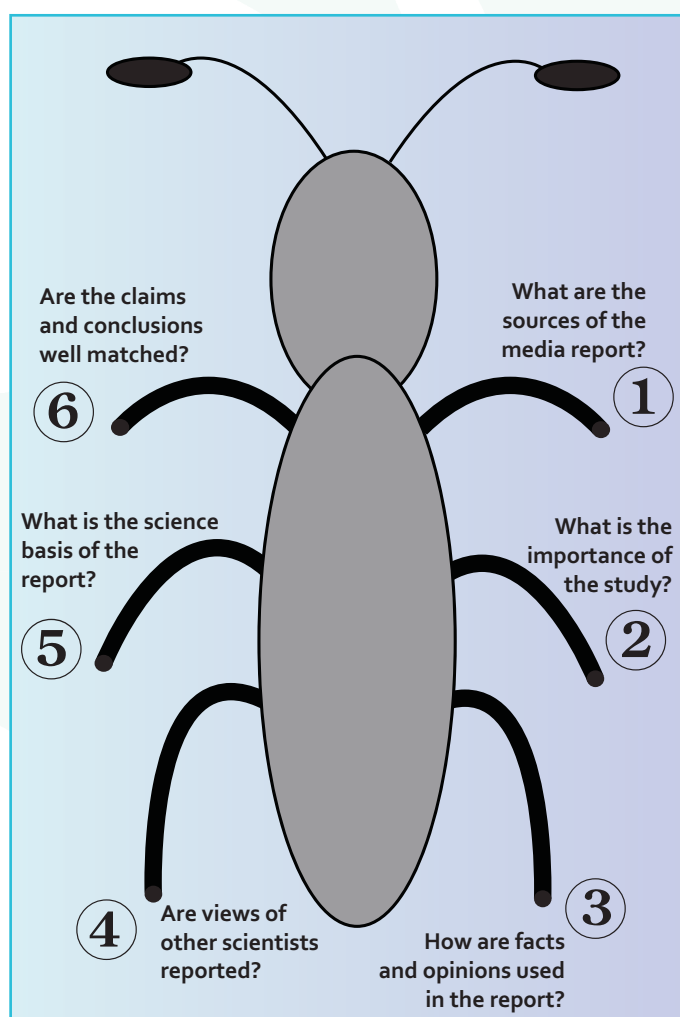


Figure 3: News Bug outline question framework

'Researchers claim that the micro-needles are painless. Each small, cone-shaped "needle" is around 600µm long (just over half a millimetre) and they do not touch the nerves beneath the skin.

'The work is still at the experimental stage. Scientists report that, using micro-needle patches, they can detect drugs such as caffeine in the body. Groups of volunteers have tested the micro-needles. In these tests, volunteers say there is no discomfort and further trials are planned.'

Figure 3 illustrates the key questions in each area. The News Bug questions used by pupils in this study, along with supplementary questions, are set out in Appendix 1.

The scientists referenced in this report are unnamed and there is no indication of their expertise in this field, though the name of the university is included. Neither complementary nor contradictory views of others in the science community have been included.

The language of the report is factual and moderate, acknowledging that the work is experimental and that more tests are planned. Pupils might use this information to make a judgement about the

plausibility of the report. The researchers' claim that micro-needles are painless is reported. The supporting evidence is based on two elements of data. Firstly, the dimension of the micro-needle – it is too short to reach the nerves and, secondly, reports from volunteers who tested the needles said they were painless, though pupils may question if any of these volunteers were primary school children? Pupils reading critically and applying the key questions may conclude that the article, in the area of science-based reporting, is reliable.

In the classroom, this activity stimulated discussion among pupils with occasional appropriate interventions from the teacher, sometimes to provide information to overcome an obstacle or ask a question to refocus a conversation. Elements of these discussions are evident in the final responses made by groups when explaining their reasoning in relation to the number of legs they gave their News Bug.

Two examples of responses from different groups to the question of inclusion of the views from other science sources give some indication of the thinking that may underpin the discussion activity. One group decided that the absence of other sources was a weakness, stating:
'It [the report] does not say that other scientists' opinions were brought into the report. They did get information from volunteers but scientists would be more experienced.'

In this example, the volunteers were acknowledged, but not as experts. Pupils commonly misunderstood references to volunteers as evidence of what other scientists think. For many pupils, this volunteer evidence was sufficient to validate the article, though not in the specific example given above. One group discussion had an insightful, if unconventional, opinion about the lack of comment from other scientists. They suggested that the absence of other scientists' views is reasonable because:

'...scientists in Ireland have made the discovery but won't tell scientists in other countries...because people in other countries could have more money and develop the micro-needles faster'.

There is some evidence here of very practical thinking about the development of technology.

This comment presents an opportunity for pupils to learn about how science knowledge is validated and expanded through co-operation and the acknowledgement of sources. This is an example of the type of conversation where the class teacher's confidence and background knowledge may enable him/her to exploit a learning opportunity. Further examples of pupils' writing (sample responses to News Bug questions) and comment on the responses are presented in Appendix 1.

Researchers analysed and coded the group responses to the News Bug tasks. Typically, these were in the form of written text to support the physical model as illustrated in Appendix 1 (Table 1). The theoretical framework for analysis categorised responses as insightful, accurate or naïve:

- An *insightful* response – shows awareness of other points of view and /or consequences
- An *accurate* response – makes use of direct quotation or reference to the text as supporting evidence
- A *naïve* response – demonstrates uncritical acceptance or rejection of text. Likely to attribute certainty to familiar, celebrity or well-known sources.

The Sketch-pad activity

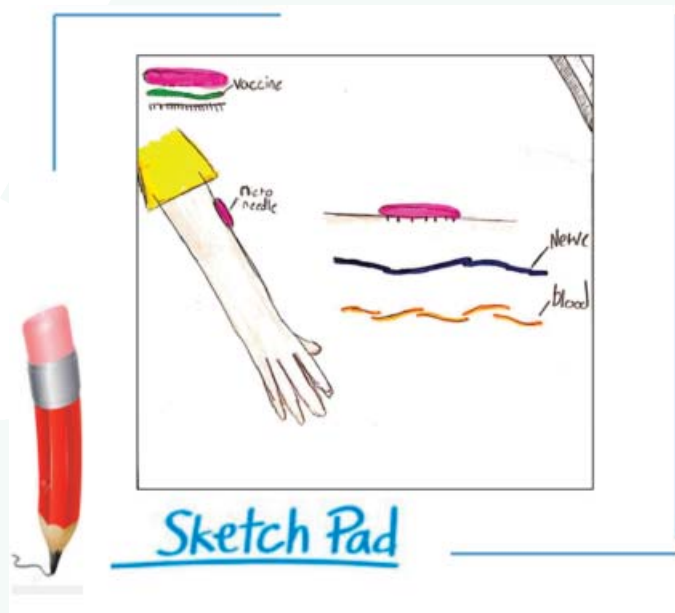
The Sketch-pad was intended to provide information about pupils' ability to read and access science content knowledge from the media text. Pupils highlighted specific elements of the written text that related to core science ideas underpinning the media report. The media report related to the development of an innovative approach to drug delivery and monitoring and the underlying 'big ideas' included the structure and function of skin as a human body organ. The media report placed the topic in context and the article, *More needles means less pain*, also reports that:

'Micro-needles only penetrate the skin's outer layer where the medicine leaks out...'

'It is safe and easy to get rid of used micro-needles because there is no risk of contamination. Used micro-needles are not dangerous because they never come into contact with blood...'

'Around 300 micro-needles are arranged on a backing layer patch no larger than a postage stamp. This can

Figure 4: A pupil sketch showing Micro-needles, nerves and blood vessels



be pressed onto the skin with gentle pressure. When they enter the skin, micro-needles...are stiff but they quickly swell with fluid from under the skin's surface...'

Pupils were asked to locate and highlight elements of the text and use the information to make a graphic that could help people to better understand the news report, in particular the structure of the skin, by using their own words and phrases to label their diagram, showing how the micro-needles deliver drugs into the skin. One example of a pupil's sketch illustrating their understanding of micro-needles and the skin structure is shown in Figure 4.

Pupils working in groups shared their individual diagrams and, together, modified these to produce what they believed to be a graphic to support the text. Researchers compared these final group images to appropriately detailed textbook images. Comparison focused on structure, detail and the appropriate use of labelling in order to highlight the role that pupil-constructed images played in learning. Tippet (2016) explored this idea further. Appendix 2 (Figure 2) illustrates a template used for analysis of the pupils' drawings.

Findings

Analysis of observational data and the outcomes of pupil activity revealed patterns of pupil behaviour that demonstrated their capability to access

science-based media reports. They used key questions, and associated prompts in the form of supplementary questions, to interrogate media text. In addition, they demonstrated a firm grasp of the big ideas of science that underpinned the text and communicated their understanding effectively in the form of a science graphic.

The outcomes suggest that these fundamental tasks, while challenging, were appropriate learning experiences within the capability of the majority of pupils and justify the commitment of curricular time to this approach. In doing so, teachers would provide a foundation for further development of higher-level skills.

Observations from scrutiny of the physical models (News Bugs) and visual representations (Sketches) constructed by pupils were supplemented by other data mentioned above. Together, these provided insights into children's understandings as they shared ideas about the text in order to promote discussion and complete the tasks set by the teacher (see Appendices 1 and 2). A News Bug with two or three legs is unlikely to stand. This would suggest that pupils did not believe the article stood up to scrutiny.

News Bug data

The News Bug outcomes generated by the pupils were compared to model outcomes generated in advance of the study by science and English teachers, who had experience in reading science news critically. In comparison to the group of experienced teachers, pupils completing the tasks were 'novice readers' in the context of science media reporting. Overall, there was a high level of agreement between model outcomes generated by experienced teachers and the efforts of pupils learning to use the structured question task.

At a foundational level of critical reading of science-based news, a competent critical reader would be expected to recognise which answers to key questions were included and identify what important information had been omitted, with his/her response illustrated by the inclusion or omission of legs on the News Bug constructed.

The majority of groups, after completing the learning tasks, constructed a model with a number and location of legs that suggested a reasoned

response. By accessing the media report, identifying relevant data and extracting appropriate information, pupils demonstrated foundational critical reading skills in the context of science-based media. Analysis suggested that pupils had more difficulty evaluating some aspects of the news report than others.

In relation to the structure of the report (Q1&2), many pupils did not pay sufficient attention to the origin of the news report and the credentials of the correspondent. However, when considering the substance of the news report and its value to them, many pupils took note of its relevance to them and their family or community. When commenting on the substance of the report, one group noted the value of painless injections, suggesting that: *'It's important to my community because some people don't like going for injection so they end up spreading the sickness'.*

It could be argued that the characteristics of relevance in news media, which by design make them attractive to a wide audience, are influential in stimulating the students' critical responses. This interest could act as an anchor point from which to promote critical reading.

Similarly, when considering the plausibility of the news report (Q3&4), it was evident that pupils were not always clear about the importance of the credibility of other sources referenced in the text, and the value of support from other scientists in establishing the article as a trustworthy science-based news report. However, a majority of pupils were able to recognise the influential role of emotive, persuasive and factual language in the report. Pupils used the questions and associated prompts effectively to identify the balance between fact and opinion and the use of emotive language, and commented on the presence or absence of 'other expert voices' in the news report. When describing the text language, one group commented:

'This is factual information from researchers...but thinking micro-needles are painless when they are not so sure, that is an opinion'.

This might suggest that pupils are able to draw on literacy skills more commonly promoted in other curriculum areas and apply these in an unfamiliar science context. The media report was observed to be both a context to use, and an opportunity to develop, fundamental literacy skills.

In relation to the reliability of the news text as science-based reporting (Q5&6), some pupils were critically aware of the importance of science method and the identification of the researchers or location of the research team. One group who were concerned about the absence of details relating to the micro-needle trials noted:

'There's not that much evidence to say that it is completely painless; they haven't said any details about the volunteers. There wasn't enough information'.

In addition, some pupils were able to recognise links between claim and evidence in relation to the reliability of the report. A lack of consistency in their use of questions and prompts in this area was evident and consequently greater variation between the pupils' conclusions and the outcome anticipated by experienced readers was observed. This might suggest that the element of media reports that address science reasoning presents a greater challenge for the novice critical reader than other elements of the report. However, the critical capacity demonstrated by some pupils would suggest that, with appropriate support, this might be an achievable goal for more pupils at the upper primary level.

Some elements of the media report were open to different interpretations. In these situations, the nature of the pupils' reasoning was a key factor in assessing the level of critical thinking. Two patterns were evident in the pupil responses. Firstly, they tended to view the report more positively than critical reading of the text might have warranted. Pupils readily attributed high status to the science sources and expressed confidence in the research done by scientists, commenting, for example, that *'the scientists must know what they are doing'.* Secondly, pupils' conversation in relation to these uncertain areas was limited and lacked judgement. It was not uncommon for a decision to have been made within the group, but no coherent reason to be evident. Observations in relation to the reliability of the text might suggest that pupils are least well equipped for tasks where the outcome can reflect differing interpretations of the news text. Two contributing factors may be relevant. Firstly, pupils may lack the maturity and/or the structure for argument and negotiation and so are hindered in expressing their reasoning. Secondly, they may have insufficient practical science experience and the necessary science process knowledge. In addressing both of these deficits,

appropriate interventions by the teacher in the role of 'the more experienced other' could facilitate learning. For example, as noted previously, some pupils suggested that scientists might not share their work with others so as to keep control of the development. The teachers took the opportunity to initiate a whole class discussion about how scientists have developed a way of writing about their work so that they can learn from others. These disputed text elements, while the most challenging, may provide the greatest opportunities for dialogue and, in turn, learning in relation to critical reading.

Sketch-pad data

The 'visual representations' constructed by the pupils were compared to diagrams of the type found in age-appropriate commercial science texts. These were similar to the type of graphic teachers might have expected to use in a more structured and teacher-guided lesson about the human body. Analysis focused on structure, detail and the appropriate use of labelling in the pupils' drawings.

In the absence of prior learning, pupils based their drawing and labelling of diagrams on their interpretation of the text. Though representations offered by individuals were often incomplete, these proto-diagrams were the basis of negotiation. Observations indicated a consistent pattern of refinement from initial incomplete rough drafts to structured and labelled diagrams that were consistent with their textbook comparators. Pupils used their visual representations to communicate what they had learnt from reading the text. To achieve this, they had to piece together a number of different references to the structure of the skin and so construct knowledge.

In doing so, they were handling their own ideas and consolidating their understanding. This is an important observation, which underlines the potential to use science-related drawing to give expression to pupils' understanding of a science idea that emerges from their critical reading. The process of negotiating and agreeing on the appropriate graphic to support the news article stimulated learning conversations. The effect of this dialogue could be seen in the refined final graphic produced by the group. It was evident from the visual product that pupils were able to translate the information from the written text to a visual representation, which is an indication of learning

that is intrinsically different from memorising a textbook diagram.

It was evident and noteworthy that teachers reporting on these visual tasks indicated that some previously reticent pupils found their voices. Here, the pupils were able to demonstrate a grasp of science knowledge that they had constructed as a result of careful and critical reading and discussion of the media text. This might suggest that visualisations provide opportunities for productive dialogue that arise naturally when pupils have to negotiate between different versions of a description. Inaccurate or incomplete diagrams from others are stimuli to explore and refine knowledge. It could be argued that the absence of detailed topic knowledge among the group placed everyone at an equal level.

Conclusion

This classroom-based study provides support for the role of science media in the development of science literacy and is relevant to teachers, teacher educators and those with responsibility for curricular evaluation and development. The study demonstrated primary pupils' capacity to access appropriately selected science-based news media. The study is significant in a field where evidence from the classroom is limited, in that it provides examples of the use of science media reports to support learning in science. These findings are important for practice. They suggest that appropriate frameworks to support critical reading based on science-based reports could be beneficial in the upper primary school and should warrant the allocation of curricular time.

As evidence of critical reading, pupils demonstrated an appropriate grasp of the ability to 'question a text' in order to assess its credibility. This observation is noteworthy and would suggest that this approach should be further refined and its value as a foundation to higher levels of critical reading capability be explored. In this context, the use of dialogue to develop pupils' capacity to promote their own ideas and accommodate the ideas of others through negotiation was observed. This type of activity is key to encouraging pupils to take ownership of their ideas in the process of learning. Opportunities to exploit this through the use of media resources in the classroom should be highlighted.



The recognition by pupils of the relevance of media-reported science was noted and this contributed to the level of engagement that was observed. In particular, the efforts that pupils made to construct knowledge were evident as pupils worked with news text to understand and explain a science idea. Engaging with news text was also observed to give pupils opportunities to explore and consolidate their literacy skills in a cross-curricular context.

Teachers effectively used media resources to support critical reading in ways that they believed suited their pupils, and they gave only as much support as pupils needed to access the activities. It may be reasonable to suggest that, with experience and the benefit of evaluation, teaching strategies could be further developed. Additional support provided by teachers might focus in particular on i) evaluating the validity and reliability of scientific methods or designs, ii) claims and supporting evidence that may appear in science media reports, and iii) the skills needed to judge between contesting positions that appear to draw on the same news-based evidence to support different conclusions.

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This is a task for pupils working in groups. This activity focuses on the news resource and asks the question: Does it (the news report) stand up to scrutiny?

Pupil guidance

Use the template (Figure 1). as a model for your own news bug. Each leg represents some of the key questions we should always ask about a news report. First read the whole news report carefully. Highlight any parts that were particularly interesting and make a note of any questions you have.

Share the question cards numbered 1 – 6 among the group. Taking the questions one at a time decide if the news report helps you to answer the question. Is there enough information? If you think the news report can help you answer the question, and your group agrees, add a leg to build your group bug. Use the template to keep a note of your answers and the reasons for your decision.

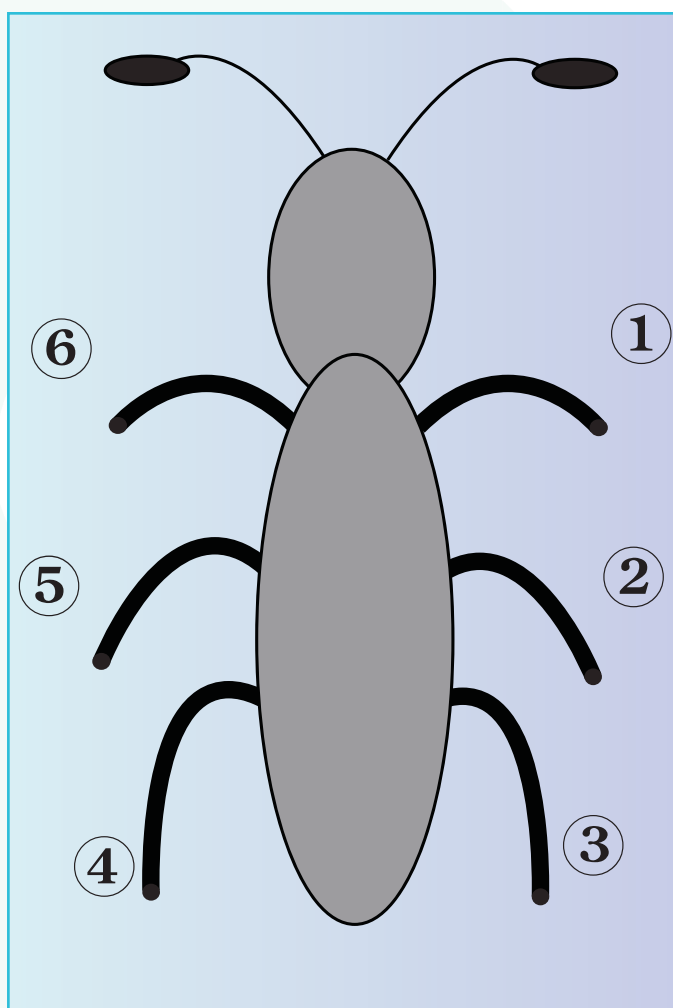
Outcomes

Pupils interrogate the text using the 6 key News Bug questions. Each main question and supplementary guidance questions focus on an important element in a credible and reliable science-based news report.

Samples of pupils' writing indicated different levels of understanding that pupils as a group demonstrated.

The responses illustrate different degrees of insight into the text (Table 1). These responses indicate the pupils' aptitude for critical inquiry and the levels of comprehension that were achieved within the group of pupils.

Figure 1: The News Bug template.



Appendix 1 Table 1: Categories of pupil responses to key questions.

Type of comment	Exemplar comments
Insightful – an awareness of other points of view and /or consequences	- It's important to my community because some people don't like going for injections so they end up spreading the sickness.
Accurate – use direct quotation or reference to the text as supporting evidence	It (the news report) does not say that any other scientist's opinions were brought into this report.
Naïve – uncritical acceptance. Likely to attribute certainty to familiar sources.	- A special correspondent wrote the news report. He uses lots of specific words like he knows how it works.

6

CONCLUSIONS

Are the conclusions or assertions supported by evidence?

Are there specific claims made?

Is there any explanation of findings or observations?

How certain are the scientists?

1

CONTEXT

What is the setting of the media report?

Who wrote the news report?

Does the writer have expertise or a special interest in the topic?

Where is the report published?

5

METHODS

What science research is the story based on?

Who did the research?

How was the research done?

Where did scientists report their work?

Is there information about new knowledge?

2

SUBSTANCE

What is the importance of the study?

What are the implications or applications of this study?

How important is it to me?

How important is it to others in my community?

4

SCIENCE SOURCES

Is there information about what other scientists think?

What do other scientists think?

Are different sources quoted?

Is there reference to other science research or knowledge?

3

USE OF LANGUAGE

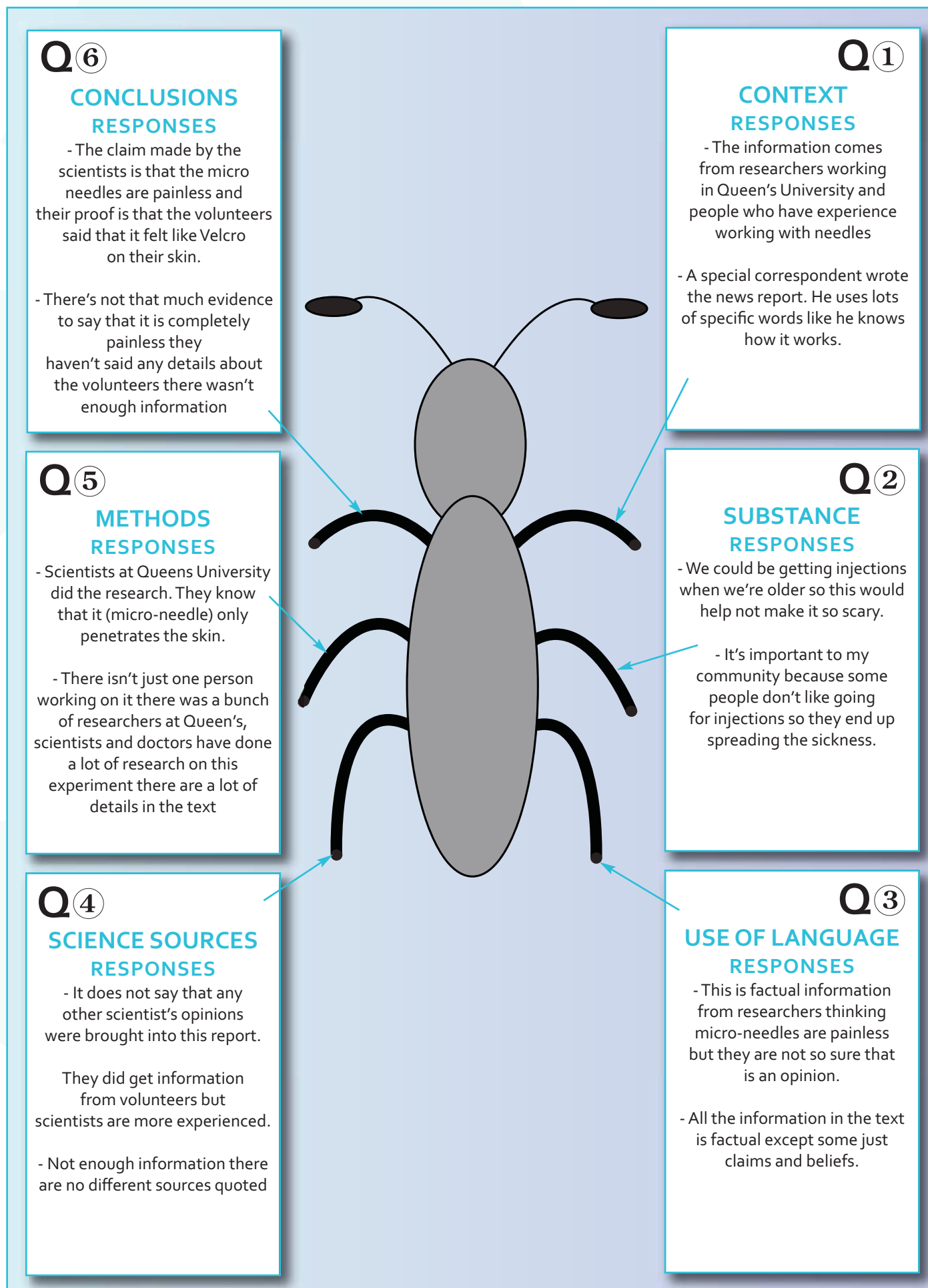
Are the main points reasonable and in agreement with facts?

Is there factual information?

Is there opinion supported by evidence?

Is the language emotive?

Are alternative views given?



Appendix 2: Sketch-pad overview

This is a task for pupils working in groups. As part of the theme of 'science in the world around us', pupils are thinking about a number of topics including the human body. The topic is contextualized using the media report about 'painless injections'. A news media report provided the stimulus resource materials. Pupils were encouraged to 'Find and highlight important words and phrases in the text'.

Pupil guidance

Use the information in the text to make a graphic (picture) that could help people understand the news report and how the micro-needles deliver drugs into the skin. Use some of your own words and phrases to complete your sketch (Figure 1).

Outcome

After reading these in context they worked in groups, using the text as reference, to talk about what they thought the micro-needles were like and how they could work to give a painless injection. They discussed the structure of the needles, the materials and importantly tried to visualize what was under their skin. The final stage was to agree what sort of graphic they could draw to could help explain how micro-needles work .



Appendix 2 Figure 1: Sketch-pad.

Samples of pupils' drawings illustrate the different levels of understanding that pupils as a group demonstrated.

The diagrams have different degrees of complexity that may indicate the different levels of understanding that was achieved within the group of pupils. In the examples shown here there is a progression from superficial to detailed. Pupil sketches were categorised as minimal, single element, complex or overview (Figure 2)

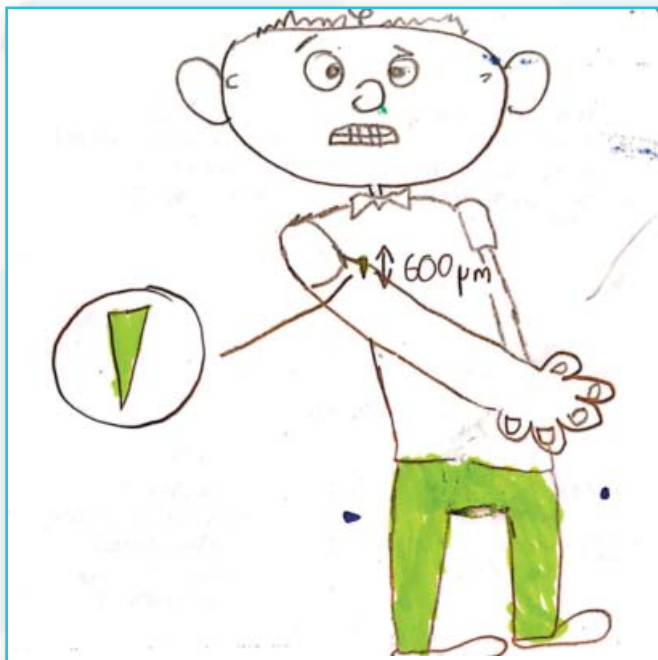
Appendix 2 Figure 2: Categories of pupil sketch

Sketch Category	Descriptor
Minimal	Sketch focuses on one specific feature
Single element	Sketch shows detailed information on a single element
Complex	Sketch shows detailed information on multiple elements
Overview	Sketch shows general description of the series of actions

Appendix 2 Figure 3: Examples of pupil sketches

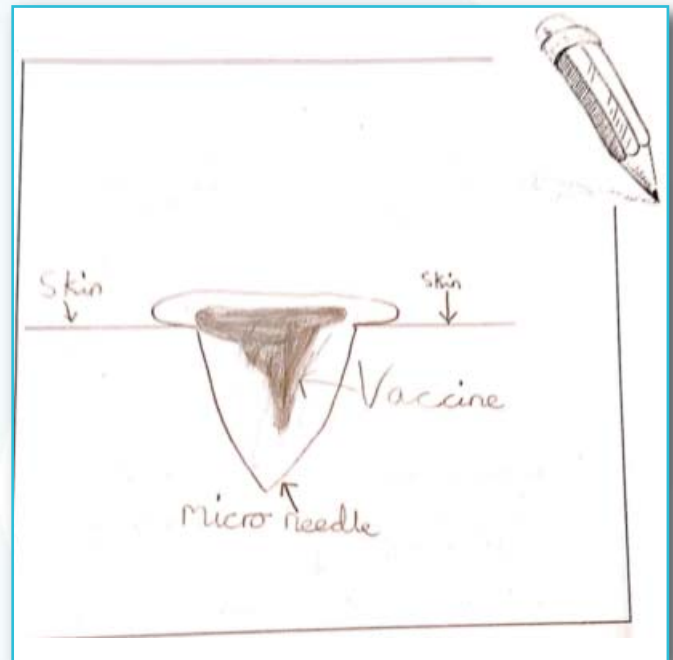
Sketch 1. Minimal –

focuses on one specific feature,
(the length of the needle).



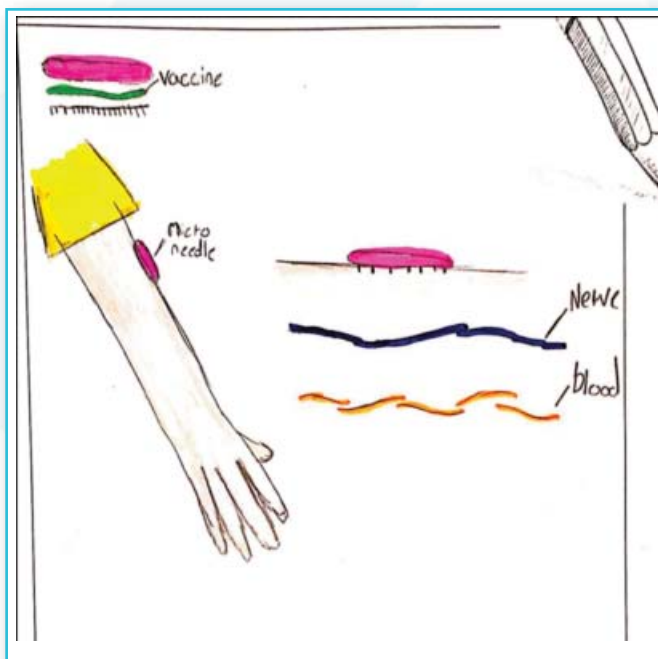
Sketch 2. Single element –

Detailed information on a single element
(the structure of the needle)



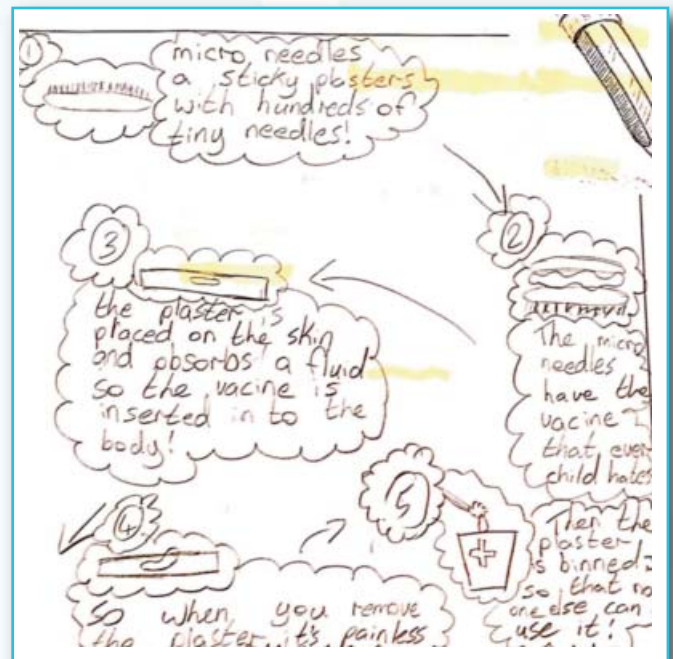
Sketch 3. Complex –

Detailed information on multiple elements
(needle patch, skin, nerves and blood vessels)

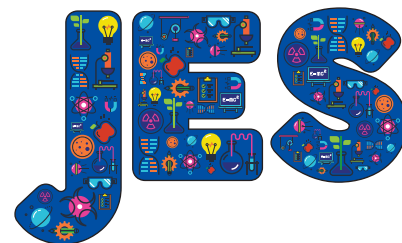


Sketch 4. Overview –

General description
of the series of actions



The challenge of balancing key principles in teacher assessment



● Sarah Earle

Abstract

The Teacher Assessment in Primary Science (TAPS) project is funded by the Primary Science Teaching Trust (PSTT) and based at Bath Spa Institute for Education. The TAPS team use a Design-Based Research approach, which involves working in partnership with schools in iterative cycles to develop products, with the aim of providing support for valid, reliable and manageable teacher assessment. This paper will explore these key principles and propose a Seesaw model to represent the challenge of balancing the requirements of validity and reliability. The balancing in the Seesaw model is suggested both as a way of conceptualising the difficulties of teacher assessment and of providing starting points for discussion of potential solutions.

Keywords: teacher assessment; primary science; TAPS; validity; reliability

Introduction

Gardner *et al* (2010) argue that teacher assessment has greater validity than formal national testing because it can be based on a wider range of evidence. This is particularly relevant for practical and collaborative inquiry-based science education (Harlen & Qualter, 2014). However, the reliability of teacher assessment is often questioned, since there is not a transparent process for making summative judgements and there may be limited opportunities for checking agreements through moderation (Black *et al*, 2011). Wiliam (2003) argues that, whilst teacher assessment can become more reliable, there is inevitably a 'trade off' between reliability and validity since, for example, an increase in reliable agreement of tightly focused question answers could lead to a decrease in the validity of the assessment, because it may not sample the whole of the curriculum. With large-scale collection of evidence and

effective moderation procedures, where teachers compare and discuss judgements, reliability of summative teacher assessment can be as high as it needs to be (Harlen, 2007), though this does raise issues of manageability.

In England, testing of primary science at age 11 was removed in 2009, but since then there has been a vacuum of advice and support, with teachers feeling concerned about how to make reliable teacher assessments (Turner *et al*, 2013: 3). High stakes testing has continued for English and maths and, whilst an Interim Teacher Assessment Framework has been released, which includes science (STA, 2015), there is little clarity about its implementation. Overall, a major concern raised by the current situation is the lack of centralised guidance for primary teachers on how to assess science. If teachers do not have an explicit view of what constitutes effective assessment in science, then it becomes difficult to decide how to make improvements in practice (Gardner *et al*, 2010). Teachers need support in developing assessment literacy to be able to make decisions about the way they use assessment (Johnson, 2012). Teacher understanding and application of assessment drives classroom practice and children's learning experiences, thus a drive to appreciate its key principles is at the heart of this paper.

The Nuffield Foundation (2012) recommended that the rich formative assessment data collected by teachers in the course of ongoing classroom work in science should also be made to serve summative reporting purposes. They developed a pyramid model whereby assessment information flowed from classroom practice to whole school reporting. The Teacher Assessment in Primary Science (TAPS) project, funded by the Primary Science Teaching Trust (PSTT) and based at Bath Spa University, employed a Design-Based Research methodology (Anderson & Shattuck, 2012) to operationalise this



model into a school self-evaluation framework. Research collaborations with local project schools, the Primary Science Quality Mark (PSQM) and PSTT College Fellows enabled the team to consider and exemplify elements of teacher assessment at pupil, teacher and whole school levels (Earle *et al*, 2015).

TAPS aims to develop support for valid, reliable and manageable teacher assessment, which will have a positive impact on children's learning. Initial TAPS findings included case studies that demonstrated a wide range of practice (Davies *et al*, 2014). Analysis of the PSQM database suggested that teachers separated formative and summative assessment (Earle, 2014). During the first three years of the project (2013-2016), teachers from twelve local schools were invited to 10 development days where a range of assessment activities were trialled. On the first day (October 2013), the concepts of validity, reliability and manageability were introduced and there was an initial discussion regarding these principles. In response to further discussions, school visits to TAPS project schools and PSTT College Fellow schools, the author developed a Seesaw-shaped model and explored this with teachers in November 2015. This paper will consider this model, which aims to conceptualise the challenge of balancing the requirements of validity and reliability.

Key concepts for teacher assessment

Before introducing a summary model of teacher assessment, it is necessary to explore what is meant by the key principles of validity and reliability. In a short article, it is not possible to consider all facets of validity; readers are directed to Stobart (2008) for more in-depth exploration; however, key elements are considered below.

Validity is essentially about checking that the assessment measures what it is meant to, the content or topics, and the skills and understanding for a particular subject. For example, in the case of primary science, a multiple-choice test would not validly assess the full range of skills and understanding of primary science; however, it could be combined with other assessments to provide a fuller picture of pupil performance. Mansell *et al* (2009) suggest that a key argument

for utilising teacher summative assessment is the way in which it enhances validity by drawing upon a wide range of information (p.12); thus, using the large amount of data collected for formative purposes could strengthen the validity. Nevertheless, there are a number of ways in which summative use of formative data could undermine the formative purpose. Torrance (2005, cited in Stobart, 2008: 157) points out that 'criteria compliance' can follow when objectives are too detailed, leading to 'assessment as learning', where the assessment becomes the goal and there is surface-level ticking or highlighting of a large number of criteria rather than in-depth learning: a 'tick-box culture' (Mansell *et al*, 2009). This also links to the mistaken assumption that frequent summative testing will support learning: *'Marks, levels, judgmental comments or the setting of targets, cannot, on their own, be formative. Pupils may need help to know how they can improve'* (Mansell *et al*, 2009: 10).

For an assessment of primary science to be valid, it needs to measure the 'constructs' or elements of primary science. Rather than debate here what is, or should be, contained within primary science, let us assume that we are aiming to assess the constructs held within the English National Curriculum (DfE, 2013). The National Curriculum lays out a Programme of Study, which contains objectives for 'Working Scientifically' (scientific inquiry) and conceptual content organised into topics like *Plants* or *Sound*. In order for a summative assessment of primary science to be valid it needs to address both the conceptual constructs and the 'Working Scientifically' constructs. **Construct under-representation** is a threat to validity (Black & Wiliam, 2012), since the key skills of working scientifically are arguably much harder to assess and thus likely to be under-represented in classroom assessments. Maintaining a focus on the science is important to avoid **construct-irrelevance**, for example, where an assessment focuses on handwriting rather than the science.

Reliability concerns the accuracy and consistency of assessments. Internal issues with tests or tasks and the conditions under which they are engaged with can be sources of unreliability (Johnson, 2012: 68) but, if teacher assessment is based on a range of information rather than a termly snapshot, then

the question of reliability becomes broader. There is the question of whether assessments are '*reliable enough*' (Newton, 2009), but many argue that teacher assessment is preferable to reliable, repeatable tests that narrow the curriculum (Wiliam, 2003), signifying a balancing act between the demands of reliability and validity. Teacher assessment based on a range of information '*enhances reliability because it provides more evidence than is available through externally-devised assessment instruments*' (Mansell et al, 2009: 12). Nevertheless, concerns regarding reliability of teacher assessment persist: '*The accountability function impedes the ability to use assessment as an integral part of the learning process, placing the teacher in a conflicted position*' (Green & Oates, 2009: 233).

A focus for reliability in the UK is on **inter-rater reliability** (Black & Wiliam, 2012: 247), which addresses whether the same judgement would be made by different teachers. Johnson (2013) asserts that there is a lack of evidence on the reliability of teacher assessment, although: '*potentially the most effective strategy for ensuring both validity and reliability in teacher assessment, if these can in principle be achieved to an acceptable degree, is consensus moderation*' (p.99). So, in primary science, inter-rater reliability would perhaps be enhanced by developing a shared understanding through moderation and exemplar material. Assessment with the sole purpose of formatively supporting the pupil with his/her next steps would arguably be less concerned with reliability, since comparison with others is not the prime purpose and the pupil is likely to have developed further his/her learning before another 'rater' attempts to assess that learning. However, without an idea of progression in scientific skills and understanding, of 'what a good one looks like', then the teacher may find it difficult to support the child in improving. '*Moderated teacher assessment has been proven to facilitate staff development and effective pedagogic practice*' (Green & Oates, 2009: 238). It appears that there needs to be some common understanding of what it looks like to 'be better' at science, to be able to fulfil both formative and summative purposes of assessment.

Analysis of the literature suggests that a key difficulty to be addressed is the need to enhance the validity and reliability of teacher assessment.

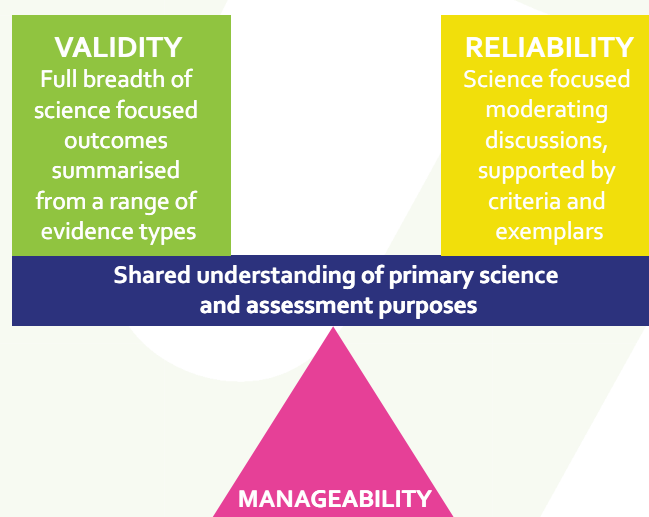
However, this requires practitioners to develop a clear understanding of these key concepts; thus, this paper aims to present a diagrammatic way to support this.

A Seesaw model of teacher assessment

One of the 'sticking points' for teacher assessment appears to be the necessary balancing act between valid assessment of the whole of a detailed curriculum, and maintaining reliable, consistent judgements – Wiliam's (2003) 'trade off' mentioned earlier. Harlen (2007: 23) states that: '*an assessment cannot have both high validity and high reliability*'; it is not possible to have highly repeatable, standardised assessment that samples the whole of practical primary science. Figure 1 attempts to represent the difficulty of retaining the validity of a broad range of information, whilst having confidence in the reliability of the judgement. The model was developed for a TAPS cluster day (November 2015) as a way of drawing together the theory of Wiliam (2003) and Harlen (2007), with the practice seen in local TAPS schools and the 'expert' schools of PSTT Fellows (Earle, 2015; Earle et al, 2015).

In order for this representation to do more than merely describe the problem for teacher assessment, the detail within the 'balance' is also designed to be supportive. The aim is to both develop teacher understanding of the terms, and also begin to suggest solutions.

Figure 1: The Teacher Assessment Seesaw: balancing validity and reliability when using formative assessments for summative purposes.



Of course, translation of such a complex issue into a Seesaw analogy diagram necessitates losing the detail of meanings discussed above, so it is accepted that this is something of a simplification to illustrate an important dilemma in assessment.

Each part of the model can be considered and related to practice:

- **Validity** is equated with providing a summary of the child's performance throughout the whole of the curriculum, which, for primary science, includes 'Working Scientifically' or scientific inquiry (to combat *construct-under-representation*), rather than just those knowledge objectives that are easily tested. The advice here is that any summative reporting should be based on a range of evidence types, which aims to reduce the *construct irrelevance*, e.g. whether the child can read the question.

- **Reliability** is supported by reference to criteria (e.g. the Interim Teacher Assessment Framework, STA, 2015), exemplars (e.g. STA (2016) exemplification, TAPS database, www.pstt.org.uk) and moderating discussions where teachers consider from different perspectives what it means for a child to have met a particular objective. Such moderation meetings with colleagues support teachers in being confident and more consistent in their judgements, but it is important that these discussions are focused on the science objectives, to avoid unconscious bias from assumptions about the child's behaviour or performance in other subjects. One of the TAPS project schools emphasises the need to 'judge the work not the child' and it is anticipated that the TAPS-focused assessment indicators will support a more objective way of judging children's scientific understanding.

- **Manageability** is explicitly highlighted at the base of the Seesaw because, if the 'weights' of validity and reliability are too onerous, the manageability fulcrum will collapse.

- **'Shared understanding'** notes the need for assessment literacy together with a secure grasp of what is contained in the subject area, since both are required for teacher assessment. The school community should work towards a shared understanding of the nature of primary science, for example, by discussing their expectations for

progression in science skills and concepts. There also needs to be a shared understanding of the purposes of assessment: that it can be primarily formative, to support pupil progress and that this can be summarised at different reporting points as necessary. If assessment is only understood in terms of testing, then it devalues the skills not easily tested, and it removes the active involvement of pupils to direct their own learning (Wiliam, 2011). Discussing formative and summative assessment, with reference to criteria and exemplar benchmarks, supports teachers in being confident and consistent in their judgements.

Much of the above draws on the Nuffield (2012) and TAPS approach: to sample the child's performance across the whole curriculum, in a manageable way that requires information gathered formatively in the classroom that can also be used for summative purposes.

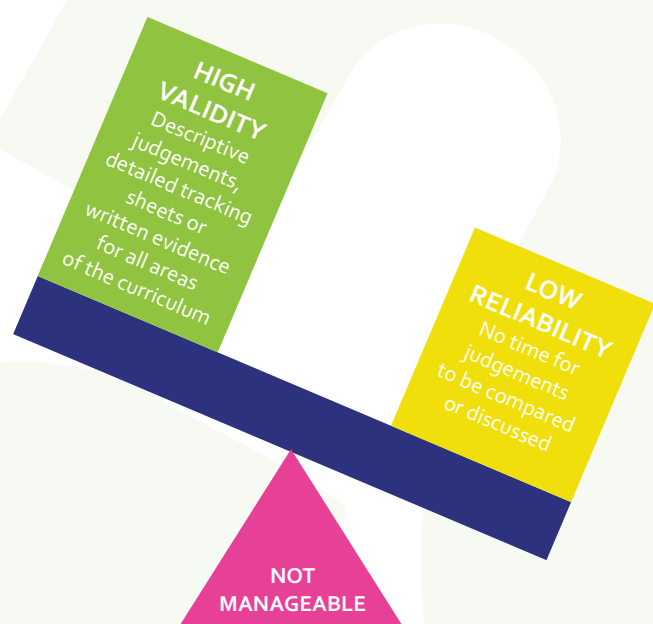
Discussion

The aim of the Seesaw balance model is to support teacher understanding of assessment, integrating the key principles from TAPS research into practice. It can be used as a discussion starter when schools are exploring assessment systems, for example, to consider how a push for narrow reliability can lead to less valid assessments. When considering the model with teachers at TAPS cluster days, many found that concrete situations were easier to discuss, for example, the end of key stage tests

Figure 2: Seesaw balance of validity and reliability for end of key stage tests.



Figure 3: Seesaw balance of validity and reliability for collection of written evidence for all judgements and children.



with high reliability and manageability but low validity (Figure 2), or the collection of detailed evidence for all objectives and children, which has high validity but low reliability and manageability (Figure 3).

An alternative stimulation for discussion could be to present teachers with a range of assessment

strategies to sort. The validity and reliability of each strategy would depend on the way it is used in class and the criteria upon which it is based; for example, teacher questioning could range from an open exploration of children's ideas to quick-fire closed questions to 'guess what is in the teacher's head'. Nevertheless, some strategies are likely to provide more reliable information upon which colleagues could agree, and other strategies could provide more valid or authentic information about what the child is able to do, but which may be hard to record or compare (see Table 1). A middle ground is presented in Table 1, where, for example, children carry out a full investigation, but only a part of this is the focus for pupil recording and teacher assessment, as recommended by the TAPS-focused assessments.

The Seesaw balance model described in this paper is designed to support understanding of assessment principles but, in order to consider the implications of this, teachers need dedicated professional development time. In primary schools, this may be a discussion that starts with the senior leadership team, or in a whole school staff meeting, rather than a sole subject leader considering changes to assessment practices alone. Moderation discussions are also a team activity; they have been highlighted as a way to improve reliability of teacher assessment, but they can also improve

Table 1: Teacher assessment strategies.

Open assessment strategies, which could be higher on validity but lower on reliability <i>(good for eliciting ideas at the start of a topic)</i>	Focused assessment strategies, which could balance validity and reliability demands <i>(good for tracking progress across the year)</i>	Closed assessment strategies, which could be higher on reliability but lower on validity <i>(good for a quick check of concepts)</i>
Pupil question-raising KWL grid (Know, Would like to know, Learnt) Mind map/thought shower Pupil drawing Concept cartoon discussion Investigation Pupil presentation Observation	Focused teacher questioning Whole investigations with focused recording of one element Choice of challenge tasks Observation supported by a 'working scientifically' tracking grid Feedback or marking focused on the objective Self/peer assessment using success criteria	Written tests Quick-fire teacher questions Multiple-choice quiz Cloze-the-gap worksheets Diagrams with pre-made labels Investigation recipe cards A directed sorting activity (only 1 way to sort)

teaching and learning (Harlen, 2007), supporting teachers in developing a better understanding of criteria and progression in a subject.

The Seesaw balance model aims to support and stimulate discussion of the purposes of assessment, but such discussions remain very abstract and removed from real practice until actual examples of children's work that has been teacher assessed are introduced. Subject leaders and classroom teachers involved in the TAPS project have found that the practical examples from real classrooms contained in the TAPS pyramid self-evaluation tool (Earle *et al*, 2015) provide suggestions that could be immediately put to use.

The Seesaw model emphasises the theory of teacher assessment, so it may need to be supplemented by examples from the TAPS pyramid to make it more accessible and immediately relevant to busy practitioners; for example, sharing strategies for recording in different ways, or exploring how to carry out moderation. However, to only look at the practical examples removed from their theoretical underpinning could lead to an adoption of strategies without an understanding of their purpose. In order to build a shared understanding of assessment, teachers need to understand their practice and judge for themselves whether changes are needed. The Seesaw model could be used to help develop assessment literacy, supporting teachers to balance the opposing forces of validity and reliability in their teacher assessment of primary science.

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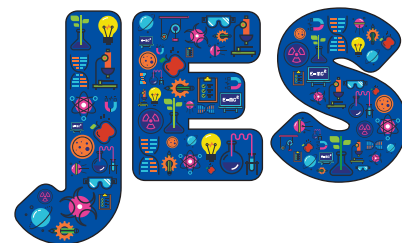
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No boundaries, No barriers: the PSTT International Primary Science Conference, Belfast, June 2016



Transforming assessment and teaching practices in science inquiry



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Abstract

ASSISTME (Assessing Inquiry in Science, Technology, and Mathematics Education) is an EU FP7 research project. In collaboration with 8 European countries, this four-year (2013-2017) project aims to find out how to support primary and secondary teachers in the formative assessment of inquiry-based learning in science, technology and mathematics.

Within this context, we developed a professional development programme that aimed to support primary teachers in their teaching and assessment of science inquiry. Our research aims to investigate how teachers transform their teaching of science inquiries and the assessment conversations that they have during classroom inquiries. This paper begins to identify what kinds of professional development experiences enable this transformation to take place.

Our data sources include written teacher reflections, audio-recordings of the professional development meetings and observed lessons and semi-structured post-lesson interviews. We draw from a multi-step, open-coding analysis of selected transcripts of the audio-recordings of classroom talk made during lesson observations. We substantiate this with teacher reflections, arising from the professional development sessions, to extend our understanding of effective ways to guide teachers in transforming their teaching and assessment practices in scientific inquiry.

Our preliminary analysis suggests that transforming the assessment and teaching of science inquiry requires some specific professional development opportunities. Sharing some examples of classroom inquiries that were bounded, initially, and then later open (Wenning, 2005) gave teachers the confidence to incorporate inquiry within their existing practice. This was introduced in conjunction with regular professional reading (Turner et al, 2011) and a focus on discrete inquiry skills (e.g. making predictions).

Collectively, this allowed teachers to sharpen their professional understanding of classroom inquiry. The critical teacher reflections, made during professional development days, supported teachers in refining their formative practice. Their assessment conversations went beyond accepting or rejecting answers and, instead, facilitated a more open and formative discussion that encouraged children to share their ideas with others.

Keywords: Inquiry, assessment, professional development

Introduction

This study forms part of a pan-European EU FP7 project, 'Assessing Inquiry in STEM Education' (ASSISTME), which is researching into classroom assessment practices during inquiry activities. There has been a series of previous projects on inquiry learning across Europe over the last decade, with a view to encouraging classroom pedagogy that supports problem-solving, collaborative learning and greater student agency.

To bring in such changes is always difficult and our hypothesis is that transforming assessment and teaching practices requires seeking ways to support teachers in recognising a need for a transformation to take place. In this paper, we share some of the research that focused on primary science practice in England. This was conducted by the King's team, in collaboration with Enfield Council, and fed into the wider European ASSISTME project. We outline some of the inquiries that were used as a vehicle for creating this teacher need for transformation and the professional development support that was developed alongside this.

We will discuss our findings through the following research question: *What enables primary teachers*



to transform their assessment and teaching practice in science inquiry and what challenges might they face in achieving this?

Background and context

Inquiry-based science education (IBSE) equips learners with a range of attitudes and skills that can support them in school and beyond (Rocard, 2007). Some of the characteristics of inquiry include questioning, reasoning and interpreting (Bernholt, Rönnebeck, Ropohl, Köller & Parchmann, 2013). These skills are often nurtured within the context of real-life, relevant inquiries that necessitate collaborative investigation and discussion. Learning in primary schools tends to focus on encouraging children to share ideas, find answers to questions and generally improve their literacy, oracy and numerical skills and these can be utilised in the IBSE classroom. As a consequence, purposeful primary science inquiry can provide rich opportunities for children to learn and for learners to share evidence of their learning through classroom talk. In these situations, teachers can pick up evidence of how well children are developing their understanding and skills and make decisions about suitable next steps in learning. These potential formative interactions are often spontaneous and transient. They rely on skilful professional ability to create suitable tasks that encourage learners to talk and engage in these formative interactions. In addition, they require a pedagogical expertise that can recognise, assess and respond to specific aspects of inquiry performance. Shalveson *et al* (2008) describe these kinds of in-the-moment assessment conversations as 'interactions on the fly'.

In England, the level of emphasis put on to the learning and teaching of primary science has been influenced by a number of wider, national requirements. These include how primary science is positioned within the National Curriculum (DfE, 2013) and within the formal summative testing requirements at the end of primary schooling in England. This position of primary science has varied considerably over the last twenty years. As a consequence, its status as perceived by teachers, learners, parents and the wider educational community has waxed and waned. This wavering status has had implications for the quality and quantity of science taught in primary schools

(Harlen, 2013; Pollard *et al*, 2000), initial primary teacher education and as part of continuing teacher professional development. These wider national circumstances have reduced the opportunities that teachers might take to instigate primary science assessment conversations. Set within this context, the UK ASSISTME research team explored how assessment conversations that take place during a lesson (*interactions on the fly*) can be used to support the learning of primary science inquiry.

For each of the Teacher Meetings, we provided input to allow the teachers to try out inquiry activities that they could adapt for their own classrooms. The overarching aim of this primary science element of the ASSISTME project was to raise teacher confidence in practical science inquiry, encourage the participating teachers to take professional risks and make primary science inquiry a more regular feature of learning. Once underway, we hoped to strengthen and transform a particular aspect of their formative practice, where using science inquiry would open up richer opportunities for teachers and learners to have assessment conversations (*interactions on the fly*) during the lesson. Later professional development could then focus on how to transform assessment practice in order to harness this assessment evidence and enable learners to make progress in science inquiry.

Nine participant primary teachers embarked on a one-year professional development programme. Enfield Council invited schools within their area to participate and, through a process of self-selection, these nine teachers were identified. The professional development involved six half-day sessions that focused on the pedagogy and assessment of science inquiry. Over the course of the year, nine inquiry lessons (see Table 1) were introduced. Resources for the inquiries were set out and the team at Enfield shared these with the teachers in such a way that these participant teachers were put in the position of the learner. This enabled the Enfield team to model the kinds of teacher questions, interactions and responses that can facilitate assessment conversations. Consequently, during professional development sessions, the participant teachers had an opportunity to do the inquiries for themselves, begin to consider how their classes might approach



these inquiries and have professional discussions with the other participant teachers about the types of resources, pedagogy and underlying subject knowledge that might be required for each inquiry. As the professional development year progressed, space was created during these sessions for the teachers to reflect on how they implemented these inquiries in their classroom. The Enfield team focused the professional dialogue around assessment evidence: *'How could you tell that progress was made? What did you notice? What did this tell you?'* These later professional discussions supported the teachers in beginning to recognise what an assessment conversation (*interactions on*

the fly) might look like within the context of a primary science inquiry.

Methods

This study follows a qualitative research approach (Cohen, Manion & Morrison, 2011). Our primary data sources draw from written teacher reflections, audio-recordings of lessons and teacher professional development meetings, combined with field notes and semi-structured post-lesson teacher interviews. Over the duration (Sept 2014–July 2015) of the project, data were collected from 6 professional development days and 10 classroom lesson observations. Within these 10 lesson

Table 1: A summary of the UK primary inquiry lessons for ASSISTME 2014-2015.

Inquiry	Summary
Mouldy bread	Children are presented with some samples of mouldy bread. In groups, they use observation, questioning and discussion to describe what they see and develop some explanations for their observations. They are then asked to investigate what conditions will keep bread mould-free for the longest amount of time.
Multi-coloured milk	In groups, children are given some yeast, water and sugar and 3 measuring cylinders. They are set with the task to investigate what is the best way to make yeast rise.
Yeast	Children are given some milk in a saucer. They are asked to observe what happens when several different food colourings are added to the milk and then washing up liquid is added in the middle. The question they are asked is 'What do you think is happening and why?'
Skittles	Children are asked to observe what happens when different coloured 'skittles' sweets are placed separately in a dish of water. How does each colour spread? Do all colours behave in the same way?
Brilliant bubbles	Children are presented with a database of possible suspects in a crime investigation. In groups, children apply their skills of deduction and reasoning to decide who is the most likely suspect and explain how the evidence they have supports this decision.
Criminal intentions	Children are given water, washing up liquid, glycerine and sugar. They are asked to investigate how to make the best bubble (biggest/strongest/lasts the longest). They are encouraged to explain their findings, e.g. 'Why does glycerine/sugar help?'
Healthy crisps	In groups, children are given a sample of several different brands of ready salted crisps. In their groups, they have to decide on a method to help them work out which is the healthiest crisp. They need to then share their findings and explanations with the class.
Drinks cooler	Children are given three drinks bottles, filled with room temperature drinking water. One bottle is wrapped up in kitchen paper, one in wet kitchen paper and one with no kitchen paper. Children then take the temperature of the water in the three bottles and then take the bottles outside on a windy day, or leave them in front of a fan for 30 minutes. The temperature of the water is taken again and they are then asked to discuss and try to explain the evidence.
Best biscuit	This combines science inquiry with technology over a series of several lessons. During these lessons, children explore (through dunking different commercially produced biscuits in warm tea), investigate and design a biscuit that they think will be the best one for taste, transportation, cost and ability to be put in a warm cup of tea without breaking up.

observations, four of the teachers were observed twice and two teachers were observed once.

A multi-step analysis was applied to all transcribed lesson data. Our interest was in how the teachers both encouraged children to offer ideas and particularly how they used these interactions to prompt formative action. This might be encouraging children to think more about an idea, or to give more detail in an answer, or to link a response with inquiry ideas that had arisen in another context. Firstly, in order to establish a unit of analysis, research field notes and the audio-recording were used to develop an overview of the lesson. This helped to identify a macro unit of analysis, in which we could select an episode where the classroom dialogue evolves around one main theme (e.g. recap from previous session). The potential for formative assessment was used to help select episodes for a finer level of analysis. In particular, episodes where children seemed to be active and offer ideas were closely examined to explore and describe the formative practices used by the participant teachers during these episodes.

Within each of the episodes, we established the micro unit of analysis, which was typically each participant's speaking turn. An open-coding approach was used to analyse this section of the transcript (Cohen, Manion & Morrison, 2011). We adopted a coding system developed by Ruiz-Primo and Furtak (2007) to analyse the episodes, referred to as ESRU coding in the literature. In this system, each fragment of the dialogue is allocated to its purpose within the interaction. So, the teacher might ask a question to elicit student thinking (E), recognise the student contribution made in response to this (R) and then, using the feedback from the student response (S), make a suggestion to help the student move forward with their thinking (U). Ruiz-Primo and Furtak explored the lesson interactions they observed to seek out complete cycles, where teachers had used the student response to make a judgement and take an action. However, we became aware that several of the episodes that we had selected because of their formative potential actually did not contain many complete ESRU cycles. This concerned us, as we could recognise the formative potential at a macro-level, but the analysis through ESRU coding was not revealing a similar finding. On careful scrutiny of the flow of the interactions, we became

conscious of several clarification attempts by the teacher within the discussion, where it seemed that the teacher was probing student ideas and encouraging other students to comment on ideas before a decision was made to take formative action. In other words, the interactions were a series of negotiation about a specific idea between the teacher and the learners aimed at developing a reciprocity of understanding.

This led our team to develop a further layer of analysis of the classroom interactions that utilised the assessment framework suggested by Torrance and Pryor (2001), to enable us to identify the teacher intention underpinning sequences of teacher speaking turns. The main advantage of our new coding system is that we could differentiate between divergent and convergent assessment approaches. Divergence occurs when teachers ask questions or make statements that instigate further thinking about the ideas being discussed, thus opening up the ideas for further consideration. For example, a teacher may ask, *'How might this evidence be used to help us answer our inquiry question?'* or *'How confident are we that we would get similar results if we repeated this inquiry tomorrow?'* Convergence happens when teachers expertly lead learners to make links with pre-determined and usually previously-met lines of thought, closes down further discussion and establishes the idea as accepted practice. In this type of interaction, a teacher might ask, *'So did we expect the mould to grow more in the warm conditions on the radiator?'* or *'Does our conclusion give a reason as well as an answer to our inquiry question?'*

Analysis

Analysis is still being finalised and the example below illustrates how the ESRU coding system is helping us to characterise the formative practice that is arising during these inquiry lessons. In a whole class discussion, the teacher encourages different groups to share how they went about their science inquiry to investigate which is the healthiest crisp. Individual students share what evidence they drew from and how they analysed this and used it to answer their inquiry question. The teacher probes (U) their thinking further by encouraging students to consider their results and apply their findings in different contexts (e.g. with a diabetic):



Teacher	Did you have anything different? How did you sort your information out, did you do quite similar to them, where you did a chart?	R, E
Student	First of all we did, we based (all of it on that ? 0:56:27) on that and then Miss told us to do this.	S
Teacher	Okay.	R
Student	So basically, so it had the least sugar, the sugar is probably the least healthy category, it had the least salt, it weighed the most, no, actually it weighed second most and it had third most calories, meaning overall, then the sugar and the salt were the main bits, having a few more calories than Pop, it made it better because those two (categories ? 0:57:20), weighing 100 more than Pop and that and Hula Hoops, didn't matter, 'cause it still really was the best.	S
Teacher	The best, what if you were diabetic though, would that influence what you thought would be healthier?	R, U
Student	Yeah.	S
Teacher	So, if I was a diabetic, which I hope I'm not, not yet anyway, which one would suit me the best, from the information you've got there, if I was a diabetic, which crisps should I buy?	U
Student	The Pops.	S
Teacher	The Pops, they've got the least sugar.	R, U
Student	Is it the one with the least sugar?	S
Student	Oh, that was [inaudible 0:57:57] Hula Hoops.	S
Teacher	It's my favourite, Hula Hoops, I'm safe with that option, okay, what about if I've got what I do have, high blood pressure, which one should I avoid?	R, U
Student	With less salt.	S
Teacher	I need the least salt.	R
Student	The least salt is...	S
Teacher	What would you advise?	E
Student	Mighty Lights.	S
Teacher	Mighty Lights, but I don't like Mighty Lights.	R, U
Student	Then don't eat crisps.	S

In terms of the ESRU coding, there are three complete cycles, but when you read the transcript and look for developing ideas and formative action being taken, it is not until the end of the 60-minute lesson. The key point in this interaction is when the teacher makes a judgement on what has been said so far and questions that by asking:

'The best, what if you were diabetic though, would that influence what you thought would be healthier?'

This question encouraged the student to rethink how they had explained their reasoning of the 'best' crisp and to redefine this in relation to the special case (i.e. the diabetic) that the teacher had suggested. So, this is an example of a divergent assessment approach, which not only challenged the child who was speaking, but also engaged the rest of the class in thinking about their results.

Conclusion

Ongoing analysis of episodes of classroom talk within the primary science inquiries begins to help us to characterise the formative practice that arises during the assessment conversations (*interactions on the fly*). An initial analysis of teacher reflections, as evidenced during professional development discussions, teacher writing and in their post-lesson interviews, suggests that dealing with ideas as they arise in the inquiry classroom can be challenging for teachers, as they attempt to transform their assessment and teaching practice. Within the context of science inquiry, these teachers need to learn how to walk a tightrope between finding a balance of promoting learner autonomy (asking probing and not leading questions), while supporting and enabling purposeful inquiry learning. For some teachers, this balance was influenced by their subject knowledge confidence, available time and their ability to allow inquiries to take different paths. The following reflection made by one of our experienced participant teachers, having taught primary for 33 years, highlights this: *'...I think I have got used to new things not working... I have got this picture in my mind of how things should be and what I would really like them all to do. It never happens...this has helped me overcome that fear of failure...doing these activities because I don't know a lot of the technical vocabulary or the science side of things as well...'* (Enfield teacher reflection, Primary PD, 13.5.15).

The findings from this research project so far indicate that transforming assessment practice requires creating opportunities for inquiry learning to take place and consequently a genuine need for formative interaction to support and enable progress. The following professional learning experiences can support primary teachers with this process:

- **Introduction of bounded and open-ended inquiries** (Wenning, 2005). Our primary project teachers found the use of closed (bounded) inquiries motivated them to start transforming their practice at the start. These inquiries gave them the structure, support and confidence to embrace science inquiry and promote this within the classroom. Towards the end of the professional development year, these teachers were introduced to more open-ended inquiries at a point when these teachers were willing to adapt and contextualise these to meet the particular needs of their class.
- **Focus on discrete inquiry skill-enabling richer and diagnostic formative interactions.** Drawing attention to a particular inquiry skill (for this project, making predictions/drawing conclusions), and creating time and space (14 weeks per skill) for learners to become familiar with this skill, secured both a teacher and learner grasp of discrete inquiry skills. When these discrete skills were unpicked, through success criteria, they also became a means of communicating with teachers and learners what successful classroom inquiry looks like.
- **Teacher engagement with professional literature.** Additional professional support was provided through the use of a teaching resource, *It's Not Fair*, (Turner, Keogh, Naylor & Lawrence, 2011). Set reading and written reflection tasks were set over the course of the professional development days and enabled the participating teachers to consider the effectiveness of the questions they used during the inquiries, their expectations of the learning arising from the inquiries, their interpretations of this and how this collectively is informing their professional understanding of the nature of science inquiry.
- **Critical self-reflection on practice and impact on learning.** A significant proportion of time and thought was dedicated to enabling teachers to



articulate their reflections on their assessment practice. These discussions were triggered by a sharing of the teaching and learning inquiry classroom experiences that took place in between professional development sessions. Through careful and expert facilitation, these reflections became the vehicle for teachers to consider how their assessment and teaching practices have been transformed. This forced an opportunity for teachers to make their subconscious formative practice explicit.

Providing teachers with inquiries and structuring these around discrete skills created opportunities for learners to reveal their understanding of science. For our primary project teachers, this emphasised the need to provide formative feedback and to develop a better ability to recognise when they were providing purposeful formative feedback and when they were not. A key implication for future research, pre-service and continuing professional development, will be to consider how to share and use examples of assessment conversations to best support teachers in refining their formative practice.

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Essential Reading for Science Teachers

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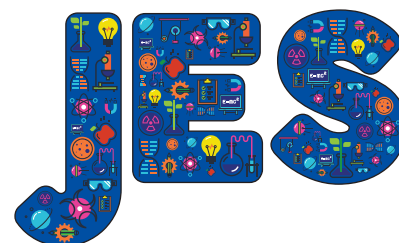
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Innovative approaches within initial Teacher Education to develop emergent science leaders



● John F. McCullagh ● Andrea Doherty

Abstract

Recent reports on primary science and technology education in Northern Ireland and the UK indicate a reduction in the amount of time allocated to science and a decrease in its profile within the primary school curriculum. It is therefore more important than ever that our science leaders possess the skills and disposition to redress this decline. We propose that, during their initial teacher education, student teachers should be encouraged to engage with curriculum development projects and have the opportunity to develop their subject leadership skills within the supportive and theory-rich environment of an Initial Teacher Education (ITE) institution. Our model of an accredited degree enhancement innovation called the 'Student Teachers' College' requires pre-service teachers to demonstrate their competence in four areas, which we feel represent the range of skills and dispositions required of an effective subject leader: excellence in classroom teaching; peer dissemination; professional development activity with schools and science education agencies; and practice-related research. This model is equally suitable for other subject areas.

Keywords: leadership; Initial Teacher Education; Professional Development; co-teaching; agency

Introduction

As Academic Collaborators for the Primary Science Teaching Trust (PSTT), we work with a large number of primary schools in Northern Ireland to develop and evaluate new forms of pedagogy in primary science. Through curriculum development projects, we aim to develop the practice of the individual teachers, enhance the schools' provision of primary science, and carry out research in the areas of science education and teacher education. A key feature of our work is the involvement of our pre-service teachers. Stranmillis University College Belfast is one of the largest providers of teachers in

Northern Ireland and offers a four-year BEd degree (primary) programme for just under 400 students, and a post-primary programme for 200 students, as well as a PGCE course and a range of programmes at Master's level. We began to involve our students in curriculum development projects as part of our research on co-teaching and quickly realised its potential to simultaneously enhance the practice of both pre- and in-service teachers (Murphy *et al*, 2004). As our model for co-teaching developed and the number of projects and partner schools increased, it became clear that many of our pre-service teachers were playing an increasing role in school development. Our student teachers' experience of working alongside in-service teachers and subject leaders to develop and modify science schemes, and the opportunity to co-teach and co-evaluate new classroom practice, develop many of the skills and dispositions required to be a future subject leader.

The starting point for producing teachers and therefore subject leaders of outstanding quality is Initial Teacher Education (ITE). However, as the prescription of what should be included within an ITE programme continues to grow, the time and capacity for primary science can be marginalised. In recent years, we have noticed a decrease in the number of incoming students choosing primary science as their subject specialism within the BEd course. This may reflect a perception that science is a less important area of the curriculum. We therefore sought a means by which the profile of primary science could be enhanced across the whole College, so that more students might engage with it during the course of their four years at the College and possibly be more inclined to include it during their placements in school and in their future practice. Based on the PSTT's (Primary Science Teaching Trust, 2016) Primary Science Teaching College, we established the 'Stranmillis Student Teachers' College' (SSTC). This model



mirrors the PSTT's Teachers' College's aim to promote and develop primary science amongst all in-service teachers, but adapts it to suit the context of ITE. Admission to the SSTC requires our students to engage with a range of activities that demonstrate their commitment to developing the practice of themselves and others. This discussion paper sets out how we feel this initiative may help to nurture and develop the science leaders of tomorrow, as well as make a significant contribution to current primary science provision.

Current context of primary science

The need for effective subject leadership in Northern Ireland is more important than ever, given the Education and Training Inspectorate's (2014) finding that the Science and Technology strand of the area of learning called 'The World Around Us' (this is where science and technology sit within the curriculum) is underdeveloped in 54% of primary schools. In these schools, the report states (p.37) that *'the provision is often too narrowly focused on low-level factual learning within isolated topics and lacks purposeful practical and investigative experiences for the children. In addition, the learning does not connect meaningfully to the children's own interests and life experiences.'* Just as unsettling is the finding that 27% of teachers believe they have insufficient knowledge and skills to teach science, in contrast to the 5% for history and 4% for geography. However, the report does highlight several examples of outstanding practice in primary science. In contrast, Northern Ireland has the highest proportion of PSTT Teaching Fellows in the UK. How then do we begin to nurture and develop a culture and practice of sharing between teachers and schools and how do we give life to the notion of a community of practice?

Although a recent Ofsted report (2013) describes the quality of teaching as 'good' or 'outstanding' in a majority of primary schools, they identify science inquiry and the regular monitoring of pupil progress to be areas for development. The report found that a very small proportion of subject leaders had received specific professional development in providing leadership for science but, where they had, the school was more likely to be 'outstanding'. Their latest report (Ofsted, 2016) found that insufficient time is being allocated to science. This was also a finding included in the CBI's

(2015) *Tomorrow's World; Inspiring Primary Scientists* report, which includes as a key recommendation that primary schools should ensure that professional development for science is of a high standard and that all schools should have a subject leader for science in place to drive a continual focus on the subject.

Lawrence (2011) points out that new subject leaders may have had few opportunities during their initial teacher training or early professional career to observe and learn from good practice in primary science teaching and leadership, and cautions that subject leadership training can be limited to generic courses that do not address the subject and pedagogical knowledge needed to support colleagues. It is notable that not one of the Northern Ireland Education and Training Inspectorate's recommendations from their report (2015) makes reference to the role of ITE. Surely an opportunity wasted?

The recently published vision for teacher professional development in Northern Ireland, *Learning Leaders: A strategy for professional development* (Department of Education, 2015), identifies 'building Leadership Capacity' (p.5) as one of its key areas and includes, as one of its 12 policy commitments, that *'leadership skills will form an integral part of all competence development from ITE and throughout a teacher's career.'* Early career exposure to leadership can be advantageous. Roden (2003) showed how pairing newly qualified teachers with science subject leaders significantly enhanced the science practice across a number of primary schools. She argues that combining the NQT's fresh knowledge of the science curriculum with an experienced curriculum planner is beneficial to the school, the pupils, and the NQTs themselves. We propose extrapolating this approach back to the initial stage of teacher education. Being a subject leader requires a positive disposition to change and growth. Knight (2013) points out that, from the very beginning of their teacher education courses, students are more receptive and positively disposed to exploring the relationship between practice and theory than is generally believed. Initial teacher education should ensure that the future leaders of science education possess the necessary skills and competences to become critical and reflective exchangers of best practice and curriculum innovation.



The programme should include opportunities for student teachers to develop an appreciation of the value of collaboration and ensure that they have sufficient confidence and sense of agency to inform their own and other's practice. All subject leaders should possess a deep belief that change is possible and a lived experience of having played an active role in bringing it about. This may be a big ask, especially during the early years of a teaching career, but to miss this opportunity during the formative years of a teacher's career makes little sense.

Stranmillis Student Teachers' College

To become an accredited member of the Stranmillis Student Teachers' College (SSTC), students are required to submit a portfolio of evidence that demonstrates their excellent classroom teaching and their involvement in professional development seminars, either in a partner school with in-service teachers, or on the University College campus. The portfolio must include evidence of what we consider to be the four pillars of subject leadership:

- Achievement of excellence in classroom teaching;
- Involvement in peer dissemination;
- Professional development with schools and external agencies; and
- Engagement with practice-related research.

This accreditation is included within the College's Degree Enhancement Programme, where students can add to their degree qualification by undertaking additional courses. Alongside narrative accounts of their experiences, the portfolio must include sufficient information to demonstrate excellence in classroom teaching and evidence the impact of their dissemination on the practice of others. Students can also include details of any work with external science education providers. We consider the ability to make science engaging and accessible to all children through high quality teaching, and being competent and comfortable at supporting and inspiring colleagues, to be the key qualities of an effective subject leader. The task of putting together this portfolio requires the student teachers to think about how the work of a subject leader may be evaluated, both in terms of pupil learning and in relation to how the professional development of peers may be evidenced. Attaining

and maintaining a high standard of classroom teaching should be the gateway for all subject leaders. They should lead by example and serve as a benchmark for their colleagues. For our student teachers, we have found that co-teaching is a very effective way to do this.

Achieving teaching excellence through co-teaching

Co-teaching involves student teachers and in-service teachers sharing equally in the planning, teaching and evaluation of new classroom approaches. This takes place during the course of curriculum development projects, which focus on a particular aspect of pedagogy or the trialling and evaluation of a new approach or resource. The experience is quite different from the students' block placement, where time for science can be restricted and students often do not get sufficient teaching time to meaningfully follow through a complete cycle of reflection for science (Jones, 2008). This form of ITE pedagogy accommodates a collaborative approach to action research and is in line with Carter's (2015) call for student teachers to develop their own teaching '*in an environment where trainees have access to the practical wisdom of experts and can engage in a process of inquiry, in an environment where they are able to trial techniques and strategies and evaluate the outcomes*' (p.21). As is often the case, the in-service teacher may also have responsibility for leading science in the school or may be a curriculum leader for another area or Key Stage. This provides the student teacher with an experience of planning and curriculum mapping way beyond what would be possible during traditional school placement. Although there is a range of forms that co-teaching may take (Murphy, 2016; Murphy *et al*, 2014), a typical pattern involves three phases: co-planning, co-teaching and solo practice.

During co-planning, pre- and in-service teaching pairs attend a number of workshops and seminars at Stranmillis University College relating to the focus of a project: for example, *Playful Approaches to Science and Technology* or *Digital Story-telling in Inquiry-based Science*. The workshops provide the co-teachers with the opportunity to discuss the new resources or approaches, explore the theory that underpins the pedagogy, and then incorporate these approaches as they put their ideas and plans

into action back in the classroom. We also include a session that focuses on the practicalities of this new form of practice and how to make the most of the opportunities provided by co-teaching, as well as strategies to overcome any challenges that this new approach may present. Co-planning allows our students to work as equals alongside experienced teachers and therefore builds their confidence, teacher identity and agency. We consider the creation of new practice to be an essential feature of co-teaching, as now both parties are equal partners embarking on a new learning journey. This provides a very different learning dynamic to the traditional school-based placement, where the student is considered to be the 'novice' and expected to conform and replicate the current practices of the 'expert' host teacher.

The Northern Ireland Department of Education's latest publication, *Learning Leaders: A Strategy For Teacher Professional Development*, calls for a focus on 'next' as well as 'current' practice (2016, p.8). Our students get first-hand experience of planning, adopting and assessing new teaching practices. We find that a synergy is created by the experience and situated knowledge of the in-service teacher and the fresh ideas and innovation of the student teacher. Teaching alongside an experienced teacher can be invaluable to the development of classroom practice. Our students feel privileged by the opportunity to simultaneously take part and evaluate a teaching episode from 'within' the lesson itself. As roles are shared and swapped during the course of the lesson, both parties are better placed (physically as well as intellectually!), to evaluate the effectiveness of the curriculum innovation under study. This 'double experience' provided by co-teaching extends the evaluative and critical thinking skills of our students. Learning from classroom incidents is much more profound and leads to a deeper understanding when the various incidents and scenarios have been personally experienced by both co-teachers during the classroom activity and then critically analysed during post-lesson evaluation. Judgements and emergent theories regarding the various strengths or areas for further development within an aspect of the lesson can be validated or reconfigured through this discussion.

The added meaning that co-teaching brings to the task of lesson evaluation must surely go some way

to developing (on the part of the student) and possibly realigning (on the part of the teacher) the practitioner's disposition to the concept of reflection. It presents reflection as manageable, valuable and powerful. We have noticed that students who have experienced co-teaching usually attain higher grades during their subsequent school placements. This is particularly true for students who may have initially struggled to cope with the full demands of classroom life. They find that co-teaching is much more supportive than solo practice. It also allows higher achieving students to continue to develop and refine their skills and to challenge themselves that little bit further. As one student recorded in her evaluation of co-teaching: *'Teaching alongside my partner teacher was amazing. I could see how she was dealing with each scenario and that when I was doing the talking and the questioning the lesson was just as good. Later, when we discussed the lesson she was just like me, analysing incidents and asking what I thought. I really felt we were a team exploring new ways and finding out what was working!'*

We have found that co-teaching between two student teachers is also very effective in developing the practice of both parties. By planning together, they bring a wider range of ideas and prior experiences that can now be explored further through discussion and possibly trialled and tested. The collaborative and co-operative approach enriches the dialogue and therefore enhances the level of critical analysis. Student-student co-teaching has also much to offer the host teacher, as the quality of the lessons being observed is usually richer than what might be expected from a student teacher working on his/her own. The host teacher can now get a real sense of what might be possible within his/her own classroom and therefore be more inclined to consider how s/he may incorporate what s/he has observed into his/her own teaching. Having a positive experience and sound understanding of co-teaching would therefore be most beneficial to a future subject leader.

In the final stage of co-teaching, we invite both partners to try and continue this approach when they have reverted back to 'solo' practice – a period often referred to as 'the January blues' by one of our project teachers, who felt bereft and vulnerable without his student partner. The final 'solo practice' phase of co-teaching aims to consolidate and

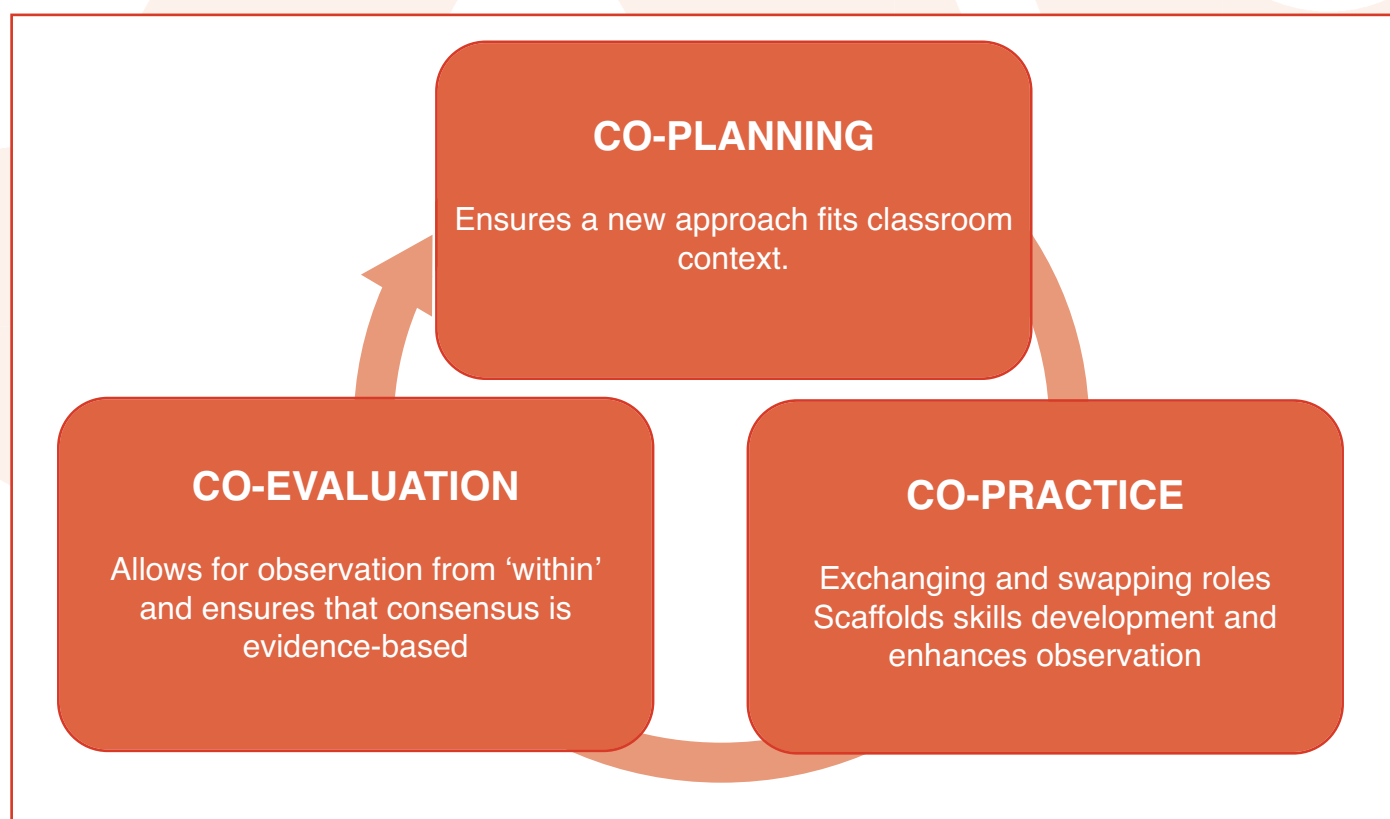
incorporate the new teaching approaches developed during co-teaching into the individual practice of each partner. We request that our student teachers include these new approaches during the course of their annual school placement. This task can prove quite challenging, as it requires adapting and transferring their practice to suit the requirements and demands of a new classroom setting. In-service teachers are required to choose an approach that they found effective during co-teaching and modify it for teaching on their own or with the support of teaching assistants. Often to their surprise, the in-service teachers find going 'solo' to be easier than they had anticipated and the resultant benefit to children's learning rewards and sustains their efforts. Our in-service teachers describe this as the most effective programme of professional development they have ever experienced, as it is situated within the context of their classroom and their needs, and the project activity and support from the pre-service students and the project leaders extend over a complete school year. This experience and understanding of co-teaching is an ideal preparation for future subject leaders who should act as mentors and critical friends for colleagues throughout their future careers.

Creating a culture of dissemination

Having a positive experience of both ends of the dissemination process – presenting their work and listening to the experiences of their peers – is key to promoting a culture of sharing and support amongst our student teachers. To enhance the status and authenticity of these experiences, we hold an annual student teachers' conference with a similar structure and protocol to an academic conference. All students, from each of the four years of the BEd programme, are invited to submit a proposal for a short presentation, an interactive workshop or a poster. The programme includes presentations on theory-informed practice based on the findings of students' research dissertations, critical evaluations of innovative approaches to science, and interactive workshops. The conference opens with a keynote lecture delivered by a science leader, such as one of the regional members of PSTT's Teachers' College.

We feel that it is vital that our students are inspired and encouraged by accounts of how effective science leadership can really enhance the quality of science provision of a particular school and the impact of this on the pupils, teachers and wider school community.

Figure 1: How co-teaching enhances the practice of both participants



Opportunities for students to engage with professional development and share ideas are provided throughout the year by a number of informal student-led workshops. These sessions are open to all students and are particularly popular in the period leading up to the students' teaching placements. Again, as with the student conference, this develops the confidence and advocacy skills of the presenters. In addition to increasing the impact of their work across a greater number of students, these student-led events instill a sense that seeking opportunities for professional growth is a central element of what it is to be a teacher. We also involve our students in the University College's annual Open Day, where they display their work and share their experiences with visiting sixth form students. Again, the aim is to develop our students' confidence and competence in promoting their work and engaging others in primary science.

External opportunities for growth

As potential future science leaders, it is important that our students are fully aware of the many opportunities for professional development beyond Stranmillis. Several of our students have presented their work at local ASE workshops and have contributed to in-service training events in partner primary schools. A group of students, from each year group of the BEd programme, attended the PSTT International Conference in June 2016. The students found the experience very inspiring and valued the wealth of ideas from the various workshops and the presentations.

A number felt the event caused them to reflect on their own practice and realise that they too have something to offer and share with the rest of the science education community. As part of their final year 'alternative placement', our students can spend two weeks working with an external science education agency such as the W5 Discovery Centre, RSPB, Ulster Museum or Armagh Planetarium.

This further develops our students' knowledge and skills, as they get to work alongside professional advocates of science and can look closely at the learning activities for a specific area of the curriculum. It also allows them to see how schools might make the most from engaging with these providers and maximise pupil learning with pre-visit or follow-up activities in their schools.

Research-related practice

Perceived 'gaps' between theory and practice (Korthagen, 2010) and insufficient continuity between student teachers' learning experiences on campus and in the school setting have been the subject of much discussion within ITE literature. The importance of attending to this possible learning dichotomy is given added significance by the recent growth of school-based models of ITE. As Donaldson (2014) cautions, more time in school doesn't necessarily result in better teaching.

The Carter review and international evidence (Sahlberg *et al*, 2014) take the view that, in high quality ITE programmes, *'theory and research need to be seamlessly linked with practice'* (Carter, 2015, p.28). The British Educational Research Association (BERA, p.3) highlights the importance of inducting their teachers *'in the use, assessment and application of research findings and that schools should be research-rich environments'...* with *'relevant research embedded at every level'*.

Engaging with practice-related research also shifts students' thinking about learning to teach and, as Korthagen *et al* (2006) put it, *'requires a view of knowledge as a subject to be created rather than as a created subject'* (p.1027). Providing all students with school placements where a thorough examination of the interplay between theory and practice can be facilitated and supported is not always possible, given the large number of students and the decrease in the number of schools willing to accommodate student teachers during placement (Hurd, 2008). In addition, there is the concern that the placement setting may not expose the student teacher to best practice (Santagata, 2007).

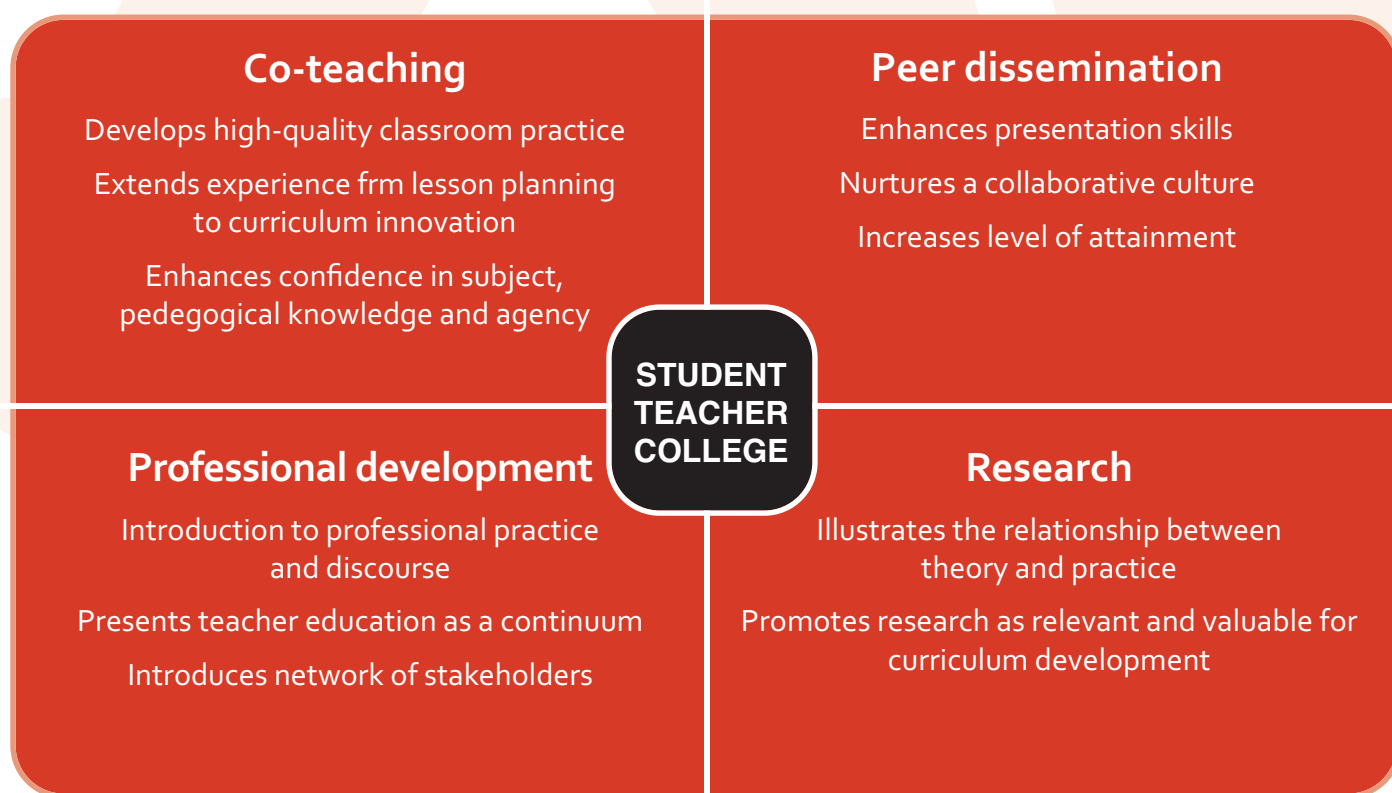
Through their participation in curriculum development projects from within the theory-rich environment of an ITE programme, our students' understanding and appreciation of the importance of research is extended. By setting theory-related research within practice, students may be less likely to consider the college-based theory-driven components of the ITE programme to be less valuable learning contexts than the practice-led placements (Hobson *et al*, 2008). Student teachers should be better placed to appreciate how research not only explains the past, but can also help create the future. These experiences can provide our students with the theoretical grounding as well as

the skills, agency and disposition to develop and lead new practice in their future careers. The Teacher Training Agency (1998, p.6) states that *'subject leaders should have knowledge and understanding of how evidence from relevant research and inspection evidence and local, national and international standards of achievement in the subject can be used to inform expectations, targets and teaching approaches'*.

Our dual roles of initial teacher educators and Academic Collaborators for the PSTT enable us to adopt a research-led approach to our pedagogy, which can inform the practice of our students and potential future subject leaders. Within their portfolio of evidence, our students must demonstrate that they have critically engaged with theory within their practice, particularly their evaluations and reflections, and show an awareness of how theory is situated and rooted within their teaching. During their annual school placement, our students spend the majority of their time teaching numeracy and literacy and therefore have only limited opportunities to teach science and fully explore the relationship between theory and practice. In addition to reducing the quality of pupils' learning experiences, limited time for

science during school placement can significantly compromise student teachers' capacity to explore the links between theory and practice. For example, when adopting an inquiry-based approach to learning, it is important to spend sufficient time to explore pupils' ideas and provide opportunities that may challenge and test their thinking, and plan activities that encourage and support pupils in discussing their ideas and emergent theories. In addition to developing the student teachers' general teaching skills, this additional time for science enables the students to fully appreciate the merits and dynamics of pupil-centred pedagogy and engage with learning theory, such as social constructivism. Through curriculum development projects or self-initiated work with a partner school, our students can plan new or modified approaches in line with a particular resource or their emergent ideas based on theory or policy. Through the analysis of nascent practice, our students can be more critical and honest in their evaluation than when following a host school's particular scheme during placement. Rather than always attempting to repeat and emulate the practice of others, they now have the opportunity to begin to explore and develop their own approaches.

Figure 2: Subject Leadership skills and attributes developed through the Student Teachers' College



However, exploring new approaches involves taking risks. As school placement is very much driven by assessment, students will often stick with a 'safe' lesson and be disinclined to teach outside their comfort zone. We must therefore look beyond the traditional form of school placement if we are to truly provide our students and future leaders with the opportunity to examine current theory and policy and challenge them to try and enact it in their practice.

Conclusion

We are not saying that our graduates already possess the experience and skills to effectively lead primary science. As newly appointed teachers, their primary focus will be on coping with the many challenges presented at the very early stage of their careers. However, we do believe that creating an environment and a culture within ITE in which students can develop their competence, confidence and sense of professional agency within a collaborative professional development experience can go some way to ensuring that they are best prepared to lead science when and where the opportunity presents itself. Activities within the Student Teacher College empower our students to take responsibility for their own development and help promote a learning ethos that may help to dissolve the boundaries between our universities and classrooms.

A decline in the perceived importance of science within primary schools will inevitably reduce its profile within the already crowded ITE curriculum. Such a reductive spiral could have serious consequences for the future. We therefore should be seeking every opportunity to enhance the profile of primary science within our university campuses and investing and trusting in our future science leaders. Just as Lightfoot (2016) calls us to 'end the myth that teachers are born not made', we believe the same can be said of subject leaders. We feel strongly that this should begin during initial teacher education.

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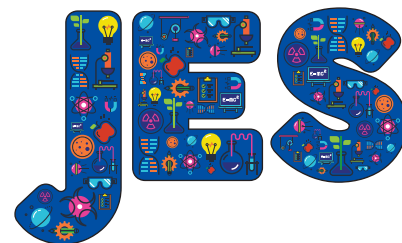
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No boundaries, No barriers: the PSTT International Primary Science Conference, Belfast, June 2016



Developing teachers as leaders of science in primary schools



● Julia Mackintosh ● Elizabeth White ● Claire Dickerson

Abstract

Children's experiences of science at primary school inform their decisions about studying science post-16, which impacts on the supply of STEM professionals. In England, the Primary Science Quality Mark (PSQM) award programme is a recognised way of addressing the reported decline in the profile given to science as numeracy and literacy have been prioritised. This programme aims to raise the profile of primary science by providing schools with a framework and professional support for developing science leadership, teaching and learning. This paper reports the views of twelve primary science leaders from schools involved in the PSQM scheme for the first time and explores changes in their attitudes to teaching and leading science. Data were collected through questionnaires, an interview and focus group and from documents submitted for the award. The findings suggest how the science leaders' perspectives shifted from science learning and practice in isolated classrooms to a whole-school vision.

Keywords: Continuing professional development; primary science; Primary Science Quality Mark (PSQM); science leaders; teacher leadership

Introduction

'Science and mathematics are essential skills for global citizens' (Royal Society and British Council, 2015, p.2). Although having plenty of future STEM (science, technology, engineering and mathematics) graduates is essential for meeting international business requirements, many countries are experiencing a shortage of graduates in STEM subjects (Royal Society and British Council, 2015). Research conducted within the UK suggests that, by the end of primary school, many children 'have already decided that the idea of studying science after the age of 16 and the idea of a career in a STEM area is "not for me"' (ESRC, 2013,

p.4). Hence, children's experiences of science at primary school are important. However, many teachers report that science has been given less of a priority in English primary schools over the past five years, often because it has been 'squeezed out with numeracy and literacy pressures' (CBI, 2015, p.15, original emphasis). Recently, teacher leadership has gained attention as a way of achieving education reform through teachers' professional development (Poekert, 2012).

As a result of their survey of 180 primary and secondary schools in England, Ofsted (the Office for Standards in Education, Children's Services and Skills), an independent inspection and regulatory organisation in England, noted that many of the participating subject leaders had not received professional development targeted at providing science leadership (Ofsted, 2013). Ofsted (2013, p.7) recommended the provision of 'subject-specific continuing professional development for subject leaders and teachers that improves the quality of assessment and feedback for pupils in science', and recognised that some school leaders had addressed the issue of the declining profile given to science through engaging in the Primary Science Quality Mark (PSQM) programme.

The Primary Science Quality Mark programme

The aims of the PSQM award programme include: raising the profile of science in primary schools; providing schools with a framework and professional support for developing science leadership, teaching and learning; and celebrating excellence in primary science. Schools can achieve an award at one of three levels, bronze, silver or gold, by demonstrating that they have met thirteen specified criteria categorised within the following four areas: subject management; teachers and teaching; pupils and learning;



and broader opportunities (PSQM, 2015). The differences between the criteria that need to be met for each level of award are illustrated in Table 1, which shows the requirements for criterion A1.

Primary school science leaders apply to take part in the PSQM programme and are appointed to local networks, called PSQM hubs. These hubs are led by PSQM-trained experts in primary science who support science leaders through the year-long programme of professional development, school-based evaluation, action planning and implementation to develop all aspects of science teaching, learning and subject leadership. During the year, the science leaders attend face-to-face workshops and receive online mentoring support from the hub leader. Working with colleagues within their schools, science leaders identify a set of actions that need to be carried out in order to meet the PSQM criteria (Table 1) and document the impact expected and the evidence that will be collected to demonstrate that each criterion has been met. The scope of the impact required for each level of award varies from a focus on the science leader's classroom for schools achieving bronze (introductory) level, to encompass the whole school (silver level) and then, in addition, to have an impact beyond the school (gold level). The PSQM process culminates in science leaders making an online submission, via the PSQM portal, of a set of reflections and supporting evidence of practice in primary science in their school to meet

the requirements for a bronze, silver or gold award. The PSQM programme is run twice a year, with 'rounds' starting in September and May.

Research methods

Research aims, participants and data collection

The main aim of the small-scale research study reported in this paper was to explore the impact of the Royal Society of Chemistry (RSC) bursary-funded PSQM scheme on the attitudes and aspirations of pupils and teachers with respect to science. The particular focus of this paper is the impact of the scheme on the attitudes of teachers towards their role as leaders of science and the findings presented here are selected from those available in the published report (White *et al*, 2015). This research study was carried out by three members of the research team at the School of Education, University of Hertfordshire. Ethical approval for the study was obtained from the relevant University ethics committee with delegated authority.

In total, twelve science leaders participated in this practice-focused study: eight from schools that started the PSQM programme in May 2014 (round 8) and four from schools that started in September 2014 (round 9). These schools were initially working at bronze level, but some of them submitted at silver level because they exceeded the descriptors for the criteria for the bronze award.

Table 1: PSQM Criterion A1: indicators for each level of award.

Criterion*	Indicators*
A1: There is an effective SL [subject leader] for science	<p>Bronze: There is an identified member of staff who oversees the subject, may have a background in the subject and can demonstrate their enthusiasm for leading it.</p> <p>Silver: There is a named member of staff responsible for the leadership of the subject. They have received subject-specific training in the last three years and have shared this with all colleagues in the school.</p> <p>Gold: The SL has shared their training and subject knowledge with a broader audience beyond their own school.</p>

*Criterion and indicators in Table 1 are taken from the *Framework for PSQM* (PSQM, 2015)

The data collection methods were as follows:

- **Self-completion questionnaire:** Two of the eight science leaders in the schools engaging in PSQM round 8 completed a questionnaire sent by e-mail.
- **Semi-structured telephone interview:** One science leader engaging in round 9 took part in a telephone interview with a member of the University research team.
- **Focus group:** Three science leaders (representing two schools registered for round 9) engaged in a focus group conducted by a member of the University research team. The PSQM hub leader and a representative from the RSC were also present during the session.
- **Data available from the PSQM portal:** Extracts from the documents submitted for the PSQM award by science leaders engaging in round 8 were reviewed for indications of attitudes towards science. As noted by Turner *et al* (2013, p.7) relating to data from the PSQM portal: *'The subject leaders are self-reporting to achieve a PSQM award. Professional and honest self-evaluation is expected, but the requirement to demonstrate that certain criteria were met might have influenced the content. Furthermore, the structure of the framework and the questions that the subject leaders responded to will have influenced their reflections.'*

Those participants who engaged in the telephone interview and the focus group were seen as 'conversational partners' in the study (Rubin & Rubin, 2011, p.7, original emphasis). An interpretive approach was taken to understand the attitudes, behaviour and thinking of the participants. Attitudes describe *'the state of being prepared or predisposed to act in a certain way in relation to particular objects, persons or situations'* and are frequently measured by individuals reporting the extent to which they agree with like/dislike statements, rather than by observing specific behaviours (Royal Society, 2010, p. 65). In this study, attitudes to science have been evaluated through self-reporting of the science leaders and through their observation and monitoring of the engagement of teachers and pupils. The science leaders were able to observe teaching and displays, scrutinise pupil work, and listen to feedback from pupil panels and from their colleagues. They also

observed informal interactions relating to the profile of science in their school.

Data management and analysis

The telephone interview was recorded and a partial transcription was prepared, which the interviewee was invited to review. The focus group was also recorded and partially transcribed. In order to preserve confidentiality when disseminating the findings, some identifiers have been removed and the following codes have been assigned: 'I/Q' for those data collected via the e-mail questionnaire, telephone interview and focus group; and 'S' for those contributed via the PSQM portal as part of the submission for the award.

The findings presented in this paper have been selected using 'purposeful sampling' (Patton, 2002, p.46) to enable a discussion of teacher leadership attitudes and activities. Some of the findings have been explored in relation to the 'Spheres of teacher leadership' conceptual model created by Fairman and Mackenzie (2012, p. 229) (see diagram on page 74 of this issue), which describes teacher leadership contexts and ways in which teachers demonstrate leadership with the goal of improving student learning. This model builds on the framework presented by York-Barr and Duke (2004), which conceptualised a route by which teacher leaders can affect student learning. York-Barr and Duke (2004, p.290) recognised formal and informal teacher leadership positioning and the fluidity of leadership functions, and suggested that *'As leaders, they influence the development of individuals, collaborative teams and groups, and organizational capacities (e.g. structures, policies, processes, resources) to improve teaching and learning in their schools'*. This fluidity of functions is apparent in Fairman and Mackenzie's (2012) portrayal of their model as nine spheres, A-I, denoting different types of leadership activity surrounding the central goal of improving student learning. This model is intended to be visualised in three-dimensions to represent the way teachers move between activities or simultaneously engage in activities within two or more spheres. Fairman and McKenzie's (2012) model has been selected as a way of exploring the findings in this study because the nature of the leadership activities, which include teachers working alone and with others both within their school and outside, aligns with the structure of the levels of the PSQM award.

Findings

Science leaders were asked about aspects of science teaching and learning (such as enjoyment and confidence), whether their attitudes to science had changed since they had been doing the PSQM programme and whether they had noticed any changes in the attitudes to science of others across their schools (other staff, pupils). For example, in the e-mail questionnaire, the science leaders were asked whether they could give any examples of specific changes that they had noticed in their own or their teachers' attitudes and thinking about science topics, or in the children's attitudes and understanding about science topics. The science leaders were also asked about changes in practice and were invited, where appropriate, to give specific examples. The findings suggest changes in the science leaders' attitudes towards the teaching of science in their own classrooms and to leading science across the whole school, as described below.

Science leaders' attitudes to teaching science

Many science leaders reported that they felt better equipped for their own teaching. Some comments were made relating to the development of subject knowledge, but most were related to science pedagogy. As one science leader said: *'I now feel much clearer about what excellent science looks like'*. As a result, science leaders reported feeling more enjoyment and confidence when teaching in their own classrooms. As one teacher reported: *'I have enjoyed teaching science more since working towards the PSQM as I am thinking more about my teaching'*. Some science leaders noted the impact that this change in attitude had on their teaching: *'I am more motivated to go away and look at things more deeply, learning on the way, with the children... I am more confident and willing to take risks [with my teaching] which is exciting because, before, I was stuck in a rut'* (I/Q). *'I am far more critical of my own teaching, I want it to be as good as it can be. It has made me look further for materials, resources and ideas'* (I/Q).

Science leaders' attitudes to leading primary science

A number of participants said that they had initially lacked confidence in leading science. One admitted it was *'quite a scary prospect'* before undertaking PSQM and another said: *'Before, I was ticking the boxes, doing observations, but I didn't really know*

what I was looking for'. Undertaking the PSQM helped science leaders to understand their leadership role, which made them feel better equipped for leading others: *'The principles are there to support it [science teaching]. So now, when I'm looking at books, when I'm looking at planning, when I'm looking at lessons, when I'm doing my own planning, I keep that in mind and I think that gives me a clear vision. It gives us forward motion – all together'* (I/Q).

Science leaders described how they shared ideas with colleagues at staff meetings, supported other teachers with planning and teaching, and monitored learning in science. They were aware of changes in how they were leading science and felt more secure in their leadership role. Responses were typified by the following: *'I have developed professionally. I'm more confident, I'm more willing to lead staff meetings and drive things forward. I do learning walks, observe lessons, book scrutinies, which is something that I have never done before'* (I/Q).

Science leaders could see how their leadership was impacting on other staff and how the attitude of other teachers had changed. Many reported that other staff were talking more about science and were more confident about using resources for teaching primary science. They were excited by the fact that there was more consistency in the quality of teaching science across the school. Pupils were being given more opportunities to work scientifically, answer their own questions and lead their own investigations. They could see that other teachers were being inspired to teach science in a more engaging way because of their leadership and that they were working collectively to develop science: *'It is empowering because it feels like I'm not on my own. There are other people with you, working towards the same goal'*. However, they also recognised that changing the attitudes of some staff was much harder than others, especially in a year of curriculum change, and they acknowledged that, for some, this was still a 'work in progress'.

Finally, science leaders could see how their leadership was impacting on pupils' motivation and enthusiasm for science: *'It's really nice to see the children who were not excited by science more engaged. It is the whole class now, not just individual children who had a flair for science'* (I/Q).

They could see how developing a wider range of learning opportunities, such as learning outside, organising visitors, special events and science trips as part of their leadership role, had enriched science teaching and learning beyond the classroom. One science leader reported feeling pride in hearing pupils explain scientific concepts to their peers and parents during a science assembly and, another, pleasure at witnessing the *'wonder and excitement on the faces of Year 1 children when animals ... arrived in their classrooms'*. Science leaders could see that their leadership had raised the profile of science within their school: *'...it's motivating because you feel like it is actually starting to work. It has taken a good six months but, slowly, through children's comments, you start to feel like I am actually making a difference'* (I/Q).

Science leaders' activities when leading primary science

To understand what the findings reveal about developing teachers as leaders of science, they were explored in relation to the nine 'spheres' of activity represented in the conceptual framework of teacher leadership developed by Fairman and McKenzie (2012). Table 2 shows some examples of the activities that the science leaders reported, categorised according to each of these spheres. This categorisation has been informed by the more detailed descriptions of the activities put forward by Fairman and McKenzie (2012). This approach to classifying the findings is tentative; it is recognised that some activities only partially meet the description and others overlap different spheres, reflecting the complexity of leadership activities in schools.

Discussion

This small-scale research study found evidence for changes in teachers' attitudes towards teaching and leading science due to their schools' engagement in the PSQM programme. Guskey (1985) suggested that changes in learning and teaching practice in class can precede changes in teachers' attitudes and beliefs, providing that this change is positively reinforced through evidence of change in pupils' learning outcomes. Thus, the changes in attitude noted in this study might have been preceded by or followed behavioural change (or both); the way that the science leaders were carrying out their role; what they were doing and how they were doing it.

Conclusion

The findings suggest that learning more about effective science teaching from the PSQM programme motivated science leaders to develop their own teaching, to 'take risks' and be more adventurous with their choice of resources. This reflects leadership activities described within spheres A and B of Fairman and Mackenzie's (2012) model (Table 2), where teachers engage with learning about, experimenting with and reflecting on their own practice. Support provided by the PSQM programme to develop subject leadership impacted on science leaders' understanding and confidence when leading science. The findings suggest that they engaged in activities described in spheres C-E: working across multiple classrooms, sharing ideas and learning with colleagues, with the aim of working collectively to develop science teaching across the school. There was also evidence that working towards the PSQM award encouraged science leaders to attend to the climate and culture of the whole school and to consider their role in the success of all students, showing engagement with activities in spheres F and G. This aligns with the aim of the silver PSQM award, which many of the participating schools achieved, even when they originally enrolled to do the bronze award. The activities described in spheres H and I align more closely with the aim of the gold PSQM award; although these might not be expected in this study, there were some indications that science leaders were engaging in activities that extended beyond their school (Table 2).

Therefore, participating in the PSQM programme facilitated movement between leadership spheres (Fairman & Mackenzie, 2012). Science leaders' perspectives shifted from a narrow focus of improving an individual teacher's learning and practice within one classroom, to broader goals of improving teacher and student learning school-wide. This relates well to the recommendation by the Wellcome Trust (2016) that: *'a primary science leader should have a whole-school vision for science and be able to lead its development by instigating appropriate initiatives, including providing continuing professional development to colleagues, monitoring progress and contributing to the strategic development of learning in school'*.

There is also evidence to suggest that the development of an effective science leader

Table 2: Science leaders' activities categorised according to teacher leadership spheres.

Spheres of teacher leadership action for learning A-I (Fairman & McKenzie, 2012, p. 231)	Examples of the science leaders' reported activities
A. Individual teacher engages in learning about his or her practice	<p><i>'I've got a degree in science so I don't think my subject knowledge has changed but I think how I teach it has definitely changed... I don't think my understanding of science has changed but I think my understanding of how children learn about science has changed.'</i> (I/Q)</p> <p><i>'I have enjoyed teaching science more since working towards the PSQM as I am thinking more about my teaching...'</i> (I/Q)</p>
B. Individual teacher experiments and reflects	<p><i>'At the start of topics I used to do the "What do you know and what do you want to find out?" But they don't really know what they want to find out until they have dipped their toes in. So now I do a lesson first and then I ask them if there is anything else they would like to know and they jot it down in their books. Then I try to cover this at some point or towards the end of a topic I ask what they still want to find out and we go and investigate it. I make a point that, if a child asks something that I don't know, we write it on the board and come back to it.'</i> (I/Q)</p> <p><i>'This time I am doing separating materials, doing solids, liquids and gases, so in hindsight the way that I'm going to teach it is different to the way I would have taught it in the past by just putting the materials out there for the children to devise their own experiments. In the past I would have given a question such as "how can we make water evaporate faster?" but I will say something like "what effects evaporation?" Getting them to think of their own questions.'</i> (I/Q)</p>
C. Teacher shares ideas and learning, mentors, coaches other teachers	<p><i>'For me the motivation comes from the fact that I am leading by example. You are the one that staff are going to come to, so you feel that you have to know things, or at least be willing to go and find out.'</i> (I/Q)</p> <p><i>'In Y6 they were looking at buzzers and created a game like "Operation", they were so enthusiastic because the teacher was more willing to take risks. They feel like they are allowed to take risks. There doesn't have to be a write-up, where "it has to be like this". I have said to them that this is fine. So this has empowered them to do this.'</i> (I/Q)</p>
D. Teachers collaborate and reflect together on collective work	<p><i>'One of the least popular areas of science learning was plant science. Since this survey, teachers have made much more use of the pond and other areas around school to develop children's understanding about plants and how they fit into the local food webs. Pupil enjoyment of plant science has increased significantly in the later survey.'</i> (S)</p>

Table 2 cont.

<p>E. Teachers interact in groups and through relationships rebuild the collaborative culture of the school</p>	<p><i>'I think [I am more confident] because I have a clear vision. I feel that the staff are on board because they also see that vision. It is empowering because it feels like I'm not on my own. There are other people with you, working towards the same goal. It is all about the children; when you see the impact on the children, it's motivating because you feel like it is actually starting to work. It has taken a good six months but, slowly, through children's comments, you start to feel like I am actually making a difference.'</i> (I/Q)</p>
<p>F. Teachers question, advocate, building support and organizational capacity</p>	<p><i>'Some staff are more willing to go on that journey and have a go. And some staff lack confidence. There is so much change [new National Curriculum] going on that they find it hard to grasp with everything else that they have to do. It is evident when you go on your learning walks that that some staff are willing to embrace it. There are more child-led investigations, they seem more confident, they are taking risks. They are allowing the children to have more control. Other staff stick to what they know best. And it's trying to move them all, slowly.'</i> (I/Q)</p>
<p>G. Teachers engage in collective school-wide improvement, focus resources, and distribute leadership</p>	<p><i>'The involvement in the PSQM has given the school a clear vision for science. In developing key principles there is a strong commitment by the teaching staff and the pupils to ensure the science that takes place adheres to these principles. We have been able to look closely at the investigative science aspect of lessons and given children more autonomy in their learning.'</i> (S)</p> <p><i>'The enjoyment of science across the school is evident whenever you walk into a science lesson – children are always engaged in their learning and completely on task. This can be seen in our lesson observations, learning walks and pupil voice evidence. During our Ofsted inspection in [date] the inspector commented that "Our learning is full of joy", which is evident from reception to year six across all subjects.'</i> (S)</p>
<p>H. Teachers collaborate with the broader school community, parents</p>	<p><i>'During PSQM, stronger links have been made with a local secondary school, which has helped cater for the needs of more able scientists in Year 6.'</i> (S)</p> <p><i>'I was collared in the playground by a parent saying "Did you know there is an eclipse on Friday?" So they know we are the people to speak to about science and they want to make sure that their children were involved in that process. We have never had that before.'</i> (I/Q)</p>
<p>I. Teacher (or group) shares work outside of school/in professional organizations</p>	<p><i>'There was also the opportunity to work with the Science Adviser and other School Science Leaders, sharing ideas for best practice.'</i> (I/Q)</p> <p><i>'I have enjoyed sharing good practice and expertise with colleagues from other schools.'</i> (I/Q)</p>

impacted on the profile of science within the school and on the attitudes of pupils, echoing the view that: '...where science has a good profile within the school as a result of dedicated leadership, and where staff are expected to teach exciting, investigative science with access to high-quality science expertise, children are likely to enjoy learning the subject' (Wellcome Trust, 2013, p.3).

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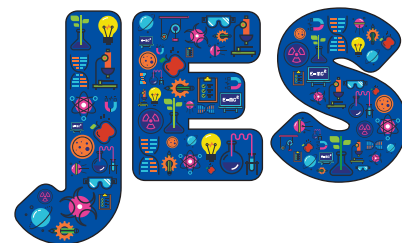
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A trajectory for the development of teacher leadership in science education



● Lynne Bianchi

Abstract

This theoretical paper presents the Trajectory of Professional Development (TOPD) as a conceptual model for teacher continuous professional development (CPD). The model's five stages are described and justified using rich descriptive statements from teachers and teacher educators working with the University of Manchester's Science & Engineering Education Research and Innovation Hub (SEERIH). The paper offers insight into the nature of professional progression and contributes to the literature on teacher leadership, by focusing more on the process of professional development from the juxtaposed perspectives of participant and teacher educator, comparing the TOPD model to that of Fairman and MacKenzie's 'Nine Spheres' (2012).

Keywords: teacher leadership; professional learning; continued professional development; science education; teacher identity

Introduction

The University of Manchester's Science & Engineering Education Research and Innovation Hub (SEERIH) offers in-service teachers a programme of continuous professional development (CPD) focused on the improvement of teaching and learning of primary school science and engineering education. Through a variety of CPD opportunities, SEERIH offers one-off showcase events, sequential courses, networking meetings, thematic or regionally-focused clusters and curriculum and research projects. The SEERIH programme acknowledges the need to recognise, appreciate, understand and respond to a learner's personal needs, which can be closely aligned with their self-efficacy, confidence and identity with science. Building on the work of Fairman and Mackenzie's nine spheres of teacher leadership (2012), and reflecting on the range of CPD experiences offered by the Hub, it has become

apparent that successful development of science teacher leaders progresses through a series of linked stages. These stages (informed by the CPD evaluative processes) are synthesised in the 'Trajectory of Professional Development' (TOPD) suggested below. The model aims to broaden and deepen understanding of the mechanisms that enable teachers to be supported in developing a professional identity as leaders in science education.

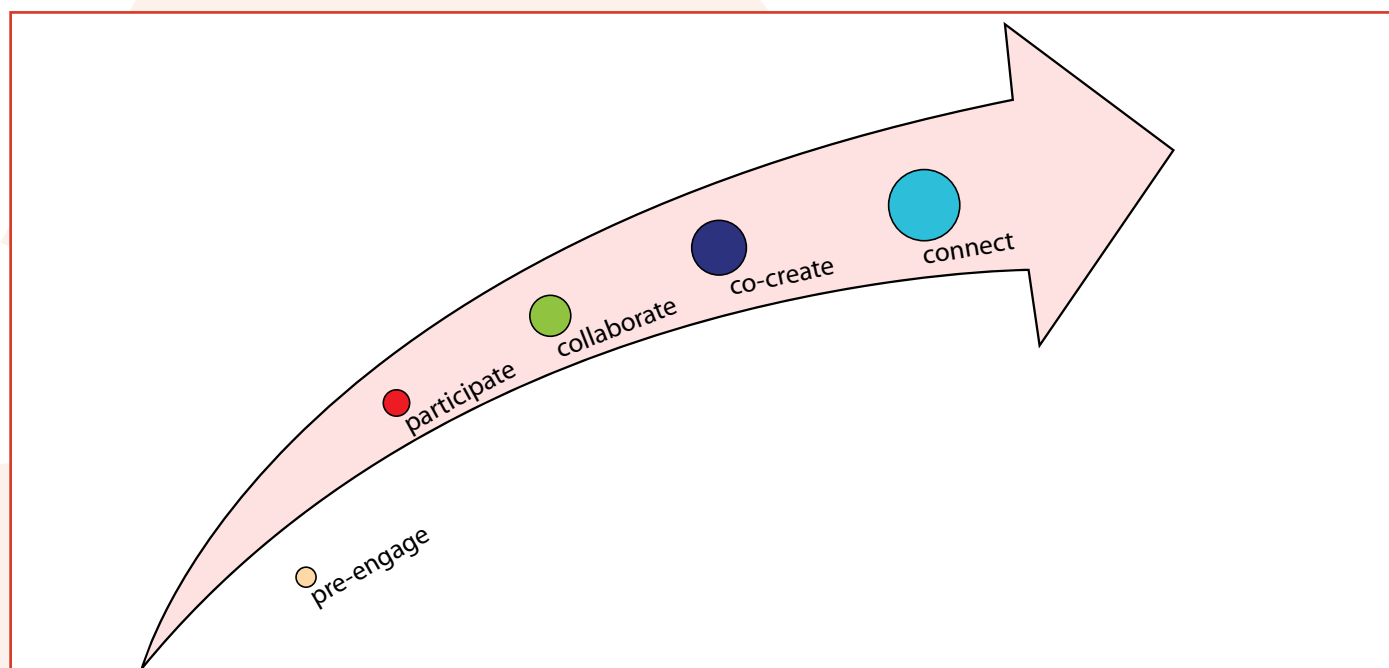
This paper therefore presents a conceptual model for teacher CPD that has been developed based on the author's professional experience over the past ten years. Reflecting on the processes in which teachers engage to become effective science leaders, there are 'key' or 'essential' stages within their CPD through which all the participants on our programmes are encouraged to progress. This theoretical paper therefore provides readers with a description, justification and exemplification of five stages of development of the conceptual framework, which other educators involved in professional development can use in their own practice.

The value of the framework is that it makes explicit many developmental processes that are implicit or almost taken for granted in one's personal and professional life. As Schon (1983) indicates, reflection is key to re-evaluating the tacit knowledge of developing practice, which can quickly become unthinking and routine. The framework offers an explicit and shared language for teachers and teacher educators to review and describe professional development, in which the five stages clarify progress during one's CPD journey.

Such reflection is in keeping with what Schon (1983: 61) refers to as 'reflection-on-action', where practitioners reflect *on* their knowing-in-practice (i.e. you as a professional developer). Griggs and McGregor (2011) suggest that '*sometimes, in the relative tranquility of the post-mortem, [teachers]*



Figure 1: The Trajectory of Professional Development (TOPD): A model for teacher leadership



think back on a project they have undertaken, a situation they have lived through, and they explore the understandings they have brought to their handling of the case.' It is this reflective activity, stimulated by the CPD framework, which has been shown to be of interest and benefit to teachers and their CPD teacher educators. It has enabled teacher educators to reflect on how the CPD experiences they develop are addressing the needs of the right teacher at the right time on the right issue: 'As an experienced provider of CPD in science education and an active member of the primary science community, the TOPD model provided a real focus on learning and the awareness that depth of learning is more meaningful than simply more and more knowledge. In the first instance, I was able to reflect in a more meaningful way when an event had not been as successful as usual. I no longer blamed the difficult audience, but recognised that there was a mismatch between where the participants sat on the arrow and the approach taken. This reflective insight then linked to the informative opportunity of the arrow to better identify the rationale, and therefore audience, of the CPD event and plan more effectively to meet a targeted need' (Teacher educator, 20 years' experience).

Background and literature

The framework ultimately supports the development of teacher leaders in educational settings and builds on literature from Frost (2003),

York-Barr and Duke (2004) and Leithwood *et al* (2004). The framework extends Fairman and Mackenzie's (2012) findings that teachers are internally driven to expand their professional knowledge and skills, experiment, take risks, collaborate, seek feedback from colleagues and question their own or others' practices. How teachers are supported to harness these motivations relates to the question of 'How are teachers prepared to lead?'. York-Barr and Duke (2004) noted that, throughout the literature, there was a call for more formal preparation and support of teacher leaders (e.g. Griffin, 1995; Ovando, 1996), and that teachers are often unsupported in their development on entry to leadership roles: 'We ask teachers to assume leadership roles without any preparation or coaching, because [we assume] they appear to intuitively know how to work with their colleagues' (Katzenmeyer & Moller, 2001, p.47).

Where such support is not provided, Katzenmeyer and Moller report a hasty retraction of teachers from leadership roles. This paper provides school leaders, educational instructors/consultants and teachers with an opportunity to categorise forms of teacher professional development that are best suited for purpose, and as such provide targeted and meaningful enrichment opportunities for staff. The current educational landscape in England places high stakes accountability measures on schools, senior leaders and teachers. Educational

reform has been strongly influenced through policy changes and related government inspection regimes. In Frost's (2003) paper on scaffolding teacher leadership, he refers to the 'command and control' approach to reform, which he suggests has taken us just about as far as it can.

He cites Horne (2001) in saying:

'Excessive centralised intervention has diminished the system's capacity to change itself and respond to wider changes that are beyond the comprehension or control of central government. The current school system in Britain is not enabling enough students or teachers to initiate change for themselves' (p.89).

As a result, the education sector has reacted by placing increased emphasis on distributed and shared leadership approaches within school. Teachers have been encouraged and promoted to

guide their colleagues in professional development and curriculum reform, through the introduction of a range of leadership roles in school, such as Subject Co-ordinators, Lead Teachers, Advanced Skills Teachers, Master Teachers, Subject Leaders and, most recently, Senior Leaders in Education. By shaping teacher leadership through such appointments, the intended outcomes have augmented the profile and influence of those in middle leadership to take on responsibility for the development and outcomes within a particular subject or area of learning.

Creaby (2013) addresses how teachers' professional identity plays a role in education reform and school improvement, whereas the development and support offered for potential candidates with aspiration for leadership often focuses on improvement of classroom practice and curricular

Figure 2: Fairman & MacKenzie's Nine Spheres model



reforms. Few recognise how a would-be leader may need to reform or redevelop their identity from that of an educational practitioner into one of a leader of others. Headteachers and senior leaders have limited opportunities for this through the National College of School Leadership schemes, where teacher development focuses on enhancing teachers' knowledge and proficiency in the dissemination of best practice and supporting other colleagues. To this end, Fairman and Mackenzie's (2012) Nine Spheres of Teacher Leadership are useful to categorise what is relevant for teachers in acting out leadership roles to advance their vision of school improvement. Their analysis provides a deeper understanding of the ways in which teachers demonstrate leadership, and the types of behaviours and interactions in which they engage to create and lead professional learning opportunities with others. Their spheres of teacher leadership for action learning include: when individual teachers engage in learning about their practice, experiment and reflect, share ideas and learn, collaborate and reflect on collective work, question, advocate and build support and organisational capacity.

Fairman and MacKenzie's spheres focus on the prime goal of improving student learning (see Figure 2) that relate to the TOPD model (see Figure 1). Common themes relating these two frameworks are the manner in which teacher leaders can be seen to participate in learning about practice; collaborate with each other; and share work outside the school (connect). The TOPD model extends that of Fairman and MacKenzie by contributing to the debate on the temporal (or longitudinal) dimension of teacher development that can occur throughout one's career, and how, over that period, the 'would-be-teacher-leaders' move across the trajectory from pre-engagement to participation, collaboration, co-creation and connection.

This paper contributes to this area of research into teacher leadership, and further develops it by bridging the gap between aspirational motives towards being a leader and the actual performing of the role. The paper promotes the TOPD model in order to explain 'how' teachers can be supported in their development – how teacher educators can facilitate the progression and development for a teacher leader. It acknowledges that, despite being

placed in a leadership position or role, a teacher needs support and opportunity to grow and develop into that role. The mere act of being awarded a new role title does not result in 'ready-made' leaders, and mentoring, coaching and support are required to bridge the transition into the leadership position in order to demonstrate and enact the role with confidence.

The 'arrow' frames the development across five stages of professional growth and the context in which it happens. The trajectory of the TOPD denotes an increasing level of ownership and autonomy that a teacher can adopt regarding his/her personal development and, in doing so, relates to the development of his/her identity as a leader. The TOPD model recognises that leadership development is defined and perhaps tightly related to a context, setting or place that has impact and influence on the teacher's position at one time.

Alongside making the progressive nature of PD more explicit, the TOPD model emphasises the importance of 'co-creation', an interactional process essential for teacher development. This is a stage of development when teachers go beyond collaborating with others to share information, explore ideas, etc. that they have received from another person, into a role where they focus on improving teaching and learning for students through the creation of their own new ideas or approaches. At this stage, they are taking what they know and have learnt to creatively explore new options, possibilities or designs for learning, whether that is an approach, a resource or behaviour.

Co-creation is a process that enables teachers to be autonomous in using their pedagogical curiosity to redefine and refine their approaches to teaching and learning, or to respond to their own educational values and philosophy in order to create new methods or processes to influence success in school. Engaging in this with others requires them to describe and justify their suggestions, build value in their suggestions with others and respond to critical feedback. By including co-creation in this framework, teachers are offered opportunities not only to respond to the reforms of others, but also to define them through their own professional voice before disseminating to others.

The TOPD model therefore provides a framework that can scaffold the development of teachers' self-awareness and agency, as they develop their identities as leaders. It highlights awareness of the different processes that come into play as the teachers progress towards becoming a leader, and of the movement between the stages of the development on the trajectory. Teachers do not have to move seamlessly between one sphere and the progressive stages of leadership, but may work their way through the different elements in a bespoke manner.

The TOPD Model: Five stages of Continued Professional Development

The Trajectory of Professional Development (TOPD) model involves five stages of development set within an upward directional arrow, which represents progress within a particular context. The stages should be viewed as essential steps or phases on the way to 'becoming' a leader (Holland *et al*, 1998), as discussed in this article, of science in a primary school. They relate to periods in a teacher's professional development career, through which s/he can progress from pre-engagement to participation to collaboration, co-creation and connection. Each stage is developmental from the last; however, teachers are not restricted in their movement between the stages. Their journey is what builds their personal profile of professional engagement.

As a teacher educator, the application of this framework is in the way that the nature of teachers' engagement in CPD is rendered more transparent, and in the tacit phases of development that aspiring teacher-leaders progress through, defined and described in ways that offer clarity and consistency of terminology and definition. The framework is rooted in the expectation that, by being more aware of, and responsive to, how teachers engage with CPD, and their motivation to change or to stay as they are, the better and more systematic our CPD offer can be. Where we work to design CPD to influence teachers' professional knowledge, skills and identity with science, we increasingly appreciate the need to differentiate the approaches that we use to maximise the impact of our efforts. We also acknowledge that, due to the increased use of social media (Twitter, Instagram, Facebook) and

the access to information on the Internet, coupled with advances in digital devices, we must revisit the range and forms of CPD that can support teachers in their professional development journey towards science subject leadership in schools.

The TOPD model offered in 2D diagrammatic form illustrates a linear and upward-orientated trajectory with clear milestones at each stage. More ideally, this should be thought of as a dynamic model, where the space between the stages affords the most learning gain, as it is here where behaviour change takes place and facilitation or support may be needed. The setting of the five stages on an arrow acknowledges how the teachers' situational contexts impact on their learning. It offers opportunity to explore how the working environment, school context and formal or informal 'spaces' for learning impact on progress and a teacher's ability to develop identity as a science educator/professional learner.

The model offers a course of trajectory from pre-engage to participate, to collaborate, co-create and connect. There is no intended judgement that one stage is 'better' than another for an individual – as the 'best' place for a teacher to be might differ due to timing, circumstance, experience and opportunity. The important thing for the individual is that his/her assessment of his/her place is accurate for that individual at that time, and responsive to the context and content of the area of development. One might place him/herself at a different stage for different areas of learning at the same time, e.g. one could identify him/herself with being a collaborator when working on biology (that individual's area of development), at the same time as being able to demonstrate the skills of a connector in an area of his/her personal specialist subject, e.g. teaching and learning.

The TOPD stages in detail

The five stages within the model that signify key moments in a teacher's professional development journey are described and considered further below.

1. Pre-engage

At this stage, the model recognises teachers who have limited access or motivation to engage with formal CPD opportunities. They could be said to be

not yet consciously active in identifying their own development needs and hence are not yet in control of enhancing their professional practice, other than in an *ad hoc*, informal way. As such they are represented in the framework as sitting outside the arrow, to illustrate that the teacher is not yet consciously aware of or responsive to potential improvement of their professional practice.

The use of an analogy can support explanation of this stage. Using the context of swimming, an individual who is at the 'pre-engage' stage will be a non-swimmer. S/he feels comfortable with this state and does not have the interest or motivation to develop swimming skills. S/he can be observed to be content with watching other people learn how to swim and enjoy swimming. S/he does not feel threatened by others in this role or by the possibility of drowning if near water.

Extensive experience has shown that, where science CPD is concerned, in-service teachers and those new to science subject leadership may have had their last formal training during pre-service or undergraduate courses. School accountability and recent austerity measures in England have found that far fewer teachers are afforded the time to develop this area of practice, with little or no support provided by Local Authority school improvement teams.

As such, within this framework these teachers are found to be 'pre-engagers', as they have not had the opportunity, motivation or support to become involved in formal CPD to develop their science subject leadership abilities. This is not to say that these teachers have no interaction with learning opportunities; for instance, they may hear about a development in a staff meeting, on social media or in the newspaper, but their engagement with it is more passive than at any other stage in the framework. To use the analogy again, they are content to hear the sound of the swimming instructor whilst watching people learn to swim.

'Before I became a science subject leader, I had received very little support in the teaching of the subject. My specialism is in music and my knowledge of how to teach science in a creative, challenging and thought-provoking way was limited. I taught science on a regular basis, but I hadn't had any opportunities to attend any science courses, so I just followed the

school science scheme on a weekly basis. When I was given science as my area of responsibility to lead, it was a fast learning curve and a huge challenge. I have accessed many things now that the University has offered, including various courses that have been so valuable. Having some one-to-one support has also had a very positive affect on my knowledge and confidence with the subject' (Teacher, 18 months into science subject leadership).

2. Participate

Active participation in CPD requires a teacher to have had an intrinsic or extrinsic motivation to engage. This may come from the Headteacher or senior leader in response to a school need, or the identification of a professional interest to self-develop. Often this occurs when a teacher adopts a position of responsibility and leadership within the school, in many cases a Key Stage or subject-related specialism. At this stage, teachers are found to be seeking out the opportunity to take part in CPD focused on a topic of interest or identified area of need. They are willing to engage in new learning, showing interest in the opinions of others. At this stage in their trajectory of development, they can be found to be scanning the landscape of opportunities in their areas of interest and looking for relatively immediate solutions to their needs.

Examples of CPD that may relate to the 'participate' stage might be attending a science public engagement event, course, network meeting or conference. Teachers may actively explore the Internet and social media for information and ideas, read a journal or go to a TeachMeet (an organised but informal meeting for teachers to share good practice, practical innovations and personal insights in teaching).

To have moved from 'pre-engage' to 'participate', the individual has begun to make the conscious decision to change. To use the swimming analogy, the individual has begun to realise a sense of need or interest, or has been required to become involved. S/he has developed a motivation to change, perhaps as a result of being told that s/he has to attend a swimming lesson (e.g. a lesson at school), or when reflecting on seeing other people having more fun than s/he is when swimming. These teachers have become interested in dipping their toes in the water and paddling in safe, shallow waters.

As a participator in CPD, the teacher is introduced to new ideas, approaches and ways of 'being' a leader and is willing to engage with it. Opportunities are usually relatively time-efficient in that the information offered is provided at an accessible and a relatively non-challenging level. What is presented can be readily adopted into classroom or school settings. The swimmer is given the building blocks, the core strokes or enhancements of current strokes that don't necessarily require greater dexterity or confidence, yet allow the swimmer to progress and increase his/her distance or speed in the water.

This extract is indicative of the change in motivation taking place as a teacher moves from 'pre-engage' to 'participate', and is illustrative of the quick-fix nature of the request for development. The teacher identifies the reasons for his interest and the motivation to engage, yet limits the engagement initially to copying or mimicking the practice of others, as opposed to the reframing and reflection on his own:

'I teach Year 5 and am Key Stage 2 Leader. I started there this year, and after a busy bedding-in year, as science leader I'd really like to kick things off next year. I thought today's meeting was great. It was great to hear of the good science going on in [my region]. It's the first time I've led science and my mantra has always been that if I'm "in charge" of something and responsible, I want to do a good job. I'd love [my school] to be involved in some projects next year and would love to work with you in really getting to grips with science, and particularly subject leadership.'

'In the meantime, my class is in the middle of a busy production and I'd like to do a great "one off" session of science inquiry. I was thinking of doing the fruit floating one that you gave us in the Spring meeting, but would like your planning or 'notes' for that lesson so I could do it well. Do you have anything you could send me? I plan to do it on Thursday of next week.'

'I'm looking forward to next year and working with you. Seeing people present today made me jealous of science in other schools and I'll do my best to get that impact in my school too' (Teacher, one year into science subject leadership, e-mail correspondence).

Teachers explained that, when engaged in this type of participation, it provided the opportunity for

'discovering new and effective ways of assessing' (Teacher, event evaluation); and *'doing "practical activities" and having discussion over different types of inquiry'* (Deputy Headteacher, event evaluation). *'[By participating with other science subject leaders I have gained] deeper understanding of the five types of working scientifically to underpin my helping other colleagues. [It has allowed me] to gain confidence and understanding of science to build science teaching in school'* (Science Subject Lead teacher, written cluster reflection).

'[By participating with other science subject leaders I have] found it most useful to have professional dialogue with other teachers and specialists. Lots of advice and information about working scientifically and how to lead this back at school. [The cluster has given me] lots of great ideas for science in school' (Science Subject Lead Teacher, written cluster reflection).

Although these CPD opportunities require participants to be actively engaged, the teacher participates mainly as a receiver and interpreter of information, with active discussion and debate to align newly developed understandings with his/her own contexts and need. Teachers gain practical solutions to issues they face and enhanced awareness of good practice in their specialist areas. Professional collaboration is limited at this stage, as the individual builds confidence, skills and understanding in their own practice. CPD experiences at this stage would rarely be designed to expose, challenge or shift a teacher's philosophy for learning in the classroom. This is not about the swimmers sharing the reasons or experiences that justify why they have not felt the need to swim before, but capitalises on the enthusiasm they have to dip their toes further in the water.

3. Collaborate

The framework illustrates how teachers progress on their journey to become leaders along a trajectory of professional learning, from acquiring knowledge at the 'participate' stage to learning alongside colleagues at the 'collaborate' stage. Collaborative learning with colleagues within and beyond the school enables teachers to interpret and make sense of ideas being presented to them, and to explore with others how these can inform and/or become embedded practices in different settings. Collaboration is the process of two or

more teachers coming together to reflect, discuss and learn through practically engaging in a task or area of development.

The 'collaborate' stage requires a level of empowerment of those taking part. This may have come as a result of increased confidence and enthusiasm developed at the 'participate' stage, or as a result of the support they feel within their school or from external sources. The 'collaborate' stage would be exemplified by the swimmers now having booked onto a course of swimming lessons, where they learn with an instructor or within a group. They have identified the need, understand the advantages of being a good swimmer and the benefits this will have on their lifestyle in the future.

At this stage in the framework, science teachers are engaged more concertedly with discussion about their own practice, the approaches to teaching, learning and assessment that they use and the reasons for their choices. It aims to engage them in identification, clarification and deeper understanding of the pedagogical approaches with which they work, as opposed to 'just good ideas'. It encourages them to get behind what's happening at surface level and to explore with others issues/needs that they face and potentially share in common. It aims to begin to actively engender a sense of partnership or community, and a responsibility as members of that community to learn with and from each other. They are required to regularly attend meetings or engage in development. The onus is on them to be willing to co-operate and contribute to enhancing a professional culture with others, by taking an active role in the group:

'This week Sam went on the science course on creative science and told me about the website of bright ideas with questions, odd one out, etc. to start lessons, etc. So I had a look on the website, I was really impressed with it. Then the Year 6 teacher told me she was struggling with planning the light and shadows unit of work, she had been on Twitter asking about it (I was quite impressed with that!). So I shared my planning with her that I did in Year 3 so she could use ideas and develop it for Year 6. I showed her the website and questions that she could use for her unit of work.'

'She just told me now that she went on the website, thought it was brill, planned the start of her unit last

night and has used the questions from the website. How good is it that she's used Sam's course to do her planning?! (and has been in touch with [other teachers on Twitter]) Should I be this excited? What is happening to me?!' (Science Subject Leader, 7 months, e-mail correspondence).

Examples of collaborative CPD opportunities might include designing and delivering a staff meeting or training event, with a colleague, to peers, regular attendance at a network meeting with teachers from the same or different schools, or being an active member of a virtual forum where teachers contribute resources and critique, e.g. Twitter, *TES Connect*, #ASEchat, Facebook groups or STEM forums. The involvement is low-risk, in that there is often another person guiding or running the meeting, the teacher's involvement is managed and the topic of focus familiar yet also developmental.

To return to the swimmer analogy, as the individual becomes more confident to try things out, there is access to buoyancy aids if required and s/he can be advised not to stray too far out of his/her depth or away from the poolside.

4. Co-create

The 'co-create' stage highlights when teachers shift from sharing learning to using and applying their new understandings in creative ways. It offers opportunity for collaborative practice, drawing individuals together who share an interest and need to create new learning around a particular theme or topic.

The creation of new ideas or experimenting with ideas in new settings and contexts can occur at this stage, when teachers and colleagues from other schools, disciplines or sectors are asked to respond to a stimulus or request, e.g. a new curriculum policy, to write a new scheme of work or to present their learning to new audiences. It is distinctive from the 'collaborate' stage, as it requests those involved to use their knowledge and experience in the development of something new or original.

It relies on the cross-fertilisation of ideas and approaches and is demonstrated best when individuals are confident and experienced in their own settings. It challenges those involved to extend and apply their knowledge to address new areas of need or interest.

The use of co-teaching acts as a 'co-create' activity, in which teachers work in twos or threes to plan, deliver and reflect on a lesson. In this practice, teachers not only collaborate and create new experiences together, but also share in their delivery, providing critical feedback to their peers (Murphy *et al*, 2013).

The motivation to move to this stage can be extrinsically triggered, e.g. the request from a senior leader, network or publisher to write a lesson plan/INSET event/scheme of work, or intrinsically triggered by the interest to explore new opportunities or contexts. To return to the swimmer analogy, those people at this 'co-create' stage are now able to swim competently, have developed basic expertise in swimming and are now able to extend what they do by developing their own adaptations. They may join forces with other swimming friends or develop family games using various swimming techniques. They develop a 'new' way of using swimming stimulated by their own creativity and ideas. Their proficiency and confidence in their technical capability is to a good standard. In moving to the 'co-create' stage, we would see the swimmer begin to explore new places and/or new people to swim with, and begin to experiment with the skills acquired to explore new situations, for example, swimming in open water rather than just the swimming pool or even learning to dive or do tumble-turns, seen by more expert swimmers as a natural progression. The adaptation of established skills into new settings is challenging and rewarding for the individual, motivating him/her to eventually want to share that experience with others.

An example of this type of engagement can be seen in this extract, from a teacher who has a passion for his area of learning. He shows in this piece how he has embraced the ideas that he developed when collaborating with peers, and extended and developed it to provide new experiences to others:

'Since I have arrived back from a wonderful visit to the Jurassic Coast, a number of things have happened. Firstly, I am a fully inspired and enthused teacher who is determined to inspire and enthuse the children as much as the trip did to me... This has already been passed onto the children in my class and we are looking at changing our summer topic to a Jurassic Coast-themed series of lessons. Secondly, I

have delivered two whole school assemblies on the Jurassic Coast. I have planned two staff meetings and a team meeting to showcase my newfound enthusiasm for Earth Science and rocks and soils. I have also started setting up links with the Jurassic Coast mentor to allow my school to write and Skype with a school on the Jurassic Coast, and with a colleague who can send more fossils and rocks to the school for further learning episodes.

'Most importantly, I have planned a scheme of work for the two Year 3 classes in the school. This consists of six practical and educational lessons to cover the rocks and soils topic in science. The Headteacher has allowed me to deliver this, as I am a Year 5 teacher, with the other teachers and university students present to showcase my science teaching and enthusiasm for this area. This will be acting as a CPD event for the teachers and students to ensure the teachers "teach science to the same high level that you do" (quote from the Senior Leadership Team). I am already looking forward to this as I get to further investigate and develop my knowledge of a fantastic area. There are lots of other things that have happened, which have developed me as a person and a teacher and I am truly grateful.

'Yesterday, I taught the first of the lessons to the Year 3 classes and they loved it. It was the late night parents evening at school yesterday as well. Two parents from the Year 3 class arrived at my door to thank me for sparking their children's interest in this area. The children arrived with a fossil and shark's tooth that they had found on holiday during half term. There is a wonderful buzz around science at the minute in school. So thank you to both of you for allowing me this opportunity to develop this area of science teaching. I haven't been this motivated to ensure teaching is so adventurous and awe-inspiring for a while and this has pushed it back to the front, ensuring all the lessons we plan and teach are going to be of a higher standard. It is something I love teaching and talking about and so far the children are loving learning about. My Year 5 class have gone home and researched and studied more on this topic and I have only told them stories so far' (Science Subject Lead Teacher for 2 years, e-mail correspondence).

Within the SEERIH programme, the 'co-create' stage has also been the stage where participants from other disciplines or sectors have become

involved in the CPD activity. On these occasions, teachers have engaged with scientists, engineers, business partners and cultural organisations who have collaborated in the design of new learning. The sharing of expertise has been challenging and has benefited from a CPD coach or mentor to facilitate the dialogue and creation process between the two groups.

Indicative experience suggests that a coach/mentor acts as a bridge between individuals from two different worlds and supports the individuals in translating language, process and knowledge between the sectors. At this stage, an individual's personal philosophy for learning is often exposed and, although time-consuming, it is reliant on all individuals having a strong sense of purpose, joint vision and drive. Further exploration of the role of the mentor at this stage is required and will be reported in a separate paper.

5. Connect

The final stage in the TOPD model is where CPD opportunities that teacher educators provide, seek out or create enable the teacher to lead the learning of others by sharing knowledge, skills and understanding. The 'connect' stage encourages teachers to explore how they can strategically disseminate their learning and benefits from a firm knowledge of methods or models for engaging adult learners. For this purpose, SEERIH uses models of learner engagement to support and develop teachers in this role, for instance models such as the 5Es Learning Cycle (Bybee *et al*, 1987).

The 'connect' stage represents when teachers' learning has become well embedded and they are willing and confident to provide support and advice to others in their own CPD journey. They are advocates of an area of expertise, able to draw on a range of experiences to allow them to listen to and meet the needs of others. This requires good communication skills and creativity, to share learning in ways that have a connection with their audience's roles, expertise and experience. It is important that the individual has the versatility to recognise the needs of the audience and the skill to model good teaching pedagogy whilst leading participant learning in suitable ways.

Examples of CPD opportunities to connect could be through publication or face-to-face training events.

Publication may take various forms, including an article in a professional journal, writing a book/chapter, conference poster, newspaper review/blog or a case study to contribute to findings in a research or evaluative report. Training opportunities may involve a conference workshop, TeachMeet presentation, creation of a teaching video or website, design and delivery of a staff training day or demonstration at a public engagement event.

To finalise the swimming analogy, this is the stage where the swimmer is able to support others to enter the water, give advice, guide and inspire others to put their toes in the water, paddle or even sign up to a series of lessons. The individual may take part in a sporting event in which s/he is an aspirational role model for wider audiences. S/he may develop the skills to teach others to swim, although this requires development of its own.

For CPD providers, it is important to recognise that 'connect' most often manifests itself as engaging other adults in the learning process, as opposed to working with children. Teachers, however skilled at teaching youngsters, therefore require opportunity and practice to build confidence in this undertaking. The following quote from a science subject leader describes his/her development as a connector:

'When I moved into my seconded role as CPD programme leader for SEERIH, my focus was on developing opportunities for Key Stage 1 science teachers. I felt a bit nervous at the start because my role was teaching children, not adults, although I held a position on the SLT. At the start, I needed quite a bit of support to make sure that the workshops went well. It was really helpful to be in the Hub and have people around who could talk about how they did their own CPD and they gave me ideas too, like using the 5Es model. The most challenging thing I found was to try to make sure I wasn't just telling people things all the time, but that I was doing things that helped them develop and learn in ways that were active and suited them. I know I still have to practice my skills more and when I can I respond to the feedback I get – but you build confidence every time you do it' (Science Subject Leader, e-mail correspondence).

Conclusion

This paper has presented the Trajectory of Professional Development (TOPD) as a conceptual model for teacher CPD, which offers the opportunity for educators to consider the nature of professional engagement in CPD and provides description, justification and exemplification of five stages of development. The theoretical framework offered here is an articulation of a work-in-progress. There is still more to do to scrutinise the nature of each stage of development. It has shown, however, that a framework for teacher educators is useful in encouraging discussion and reflection about the nature of planning for CPD opportunities. The key aspects of the model are reflected in the positive feedback that teachers provide at the different stages in their professional learning journey toward leadership.

Further use and evaluation of the framework will focus on key aspects of interest, e.g. whether the directional arrow depicting growth and extension of the skills required for leadership is fit for purpose and representative of teacher progression in CPD, and how the role of the teacher educator impacts on teacher engagement. Reflections from some teachers suggest that the arrow creates the impression that there is an endpoint to professional development. They preferred a cyclical framework, whereby a teacher would view CPD as ongoing and repeated over time. It is of interest to understand how the educator influences the motivation and ability of a teacher to move from one stage to another. What is clear is that positive and open relationships are significant at each transition point and further analysis of their impact on teacher development would be of interest.

The Appendix provides the reader with a summary of features at each stage in the TOPD model.

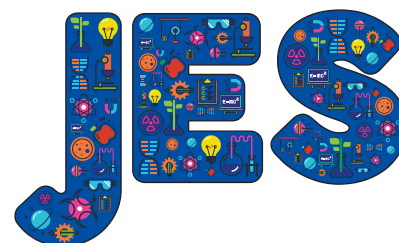
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THE STAGES	PRE ENGAGE	PARTICIPATE	COLLABORATE	CO-CREATE	CONNECT
THE INDIVIDUAL IS...					
General description	Not yet consciously active in identifying their own development need. They are not yet in control of enhancing their professional practice, other than in an <i>ad hoc</i> , informal way.	Seeking out the opportunity to take part in CPD focused on a topic of interest or identified area of need. They are willing to be around new learning, showing interest in the opinions of others.	Coming together with two or more people to reflect on, discuss and learn through practically engaging in a task or area of development together.	Moving from sharing learning with others to using and applying their new understandings in creative ways.	Leading the learning of others by sharing knowledge, skills and understanding.
Teacher motives to engage	No motivation to change, happy with the <i>status quo</i> .	Intrinsic or extrinsic motives to participate – e.g. being sent on a course by a senior colleague, or feeling the need or interest to self develop.	Intrinsic motives generated through interest in other people's practice. Extrinsic motives may be that senior leaders wish to be part of a group.	Intrinsic interest to showcase and share knowledge and expertise. Interest in being creative and exploring new learning opportunities.	Mainly driven by intrinsic interest to support and inspire others. Aspirations to be a role model or advocate.
Typical behaviours	Passive, information is received, e.g. during a meeting, via social media or in the newspaper.	Actively engaged – the receiver of information, showing willingness to discuss and interact with the information in order to align the new learning with their own contexts and need.	Actively engaged with others, discusses their own practice and can justify their choices. They learn with others, sharing and co-operating.	Actively engaged and creating through the cross-fertilisation of ideas and approaches in an endeavour to create new ideas, learning or opportunities.	Actively disseminating and supporting others. Requires good communication skills and creativity to share learning in ways that have a connection with their audience's roles, expertise and experience.

Scientist-teacher collaboration: exploring the nature of successful STEM placements in primary schools



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Abstract

This paper reports on the processes and impact of STEM volunteers working with primary schools. STEM volunteers are often undergraduate or postdoctoral science or engineering students, or professional scientists and engineers. Primary school teachers can request involvement with STEM volunteers through a range of placement schemes. The teachers involved are often those who hold specific roles for the development of science teaching, learning and assessment practices across the school. In this project, the University of Manchester's Science & Engineering Education Research and Innovation Hub (SEERIH) acted as project developer and the broker for 'setting up' the associations between the schools and the STEM volunteers. This paper reviews what a consultative group (formed from stakeholders, including teachers, STEM volunteers, SEERIH staff, STEMNET staff and University of Manchester Widening Participation staff) identified as features of successful STEM volunteer placements in primary schools, and reports on the findings, observations and interviews with the STEM volunteers and teachers about their experiences.

The approach of the project was to explore how the involvement of STEM volunteers might support or impact on the teaching of primary science. For six volunteers involved in the scheme reported on here, there is illustrative data to indicate what kinds of activities they introduced into the schools and discussion of the ways in which the teachers and children benefited from these. Reflections on the experiences of volunteers and their co-ordinating teachers appear to indicate that there are two key processes at play that appear to inter-relate with each other and influence the quality of learning science: (i) the STEM volunteer-teacher relation and (ii) the activity that arises from that relationship. The paper critically reflects upon the means and style of facilitation required to support the development of

collaborative practices between STEM volunteers and teachers for meaningful learning experiences for children.

Keywords: professional development; science education; scientist-teacher collaboration; pedagogy

Introduction

The STEM VIPS (Science Technology Engineering and Mathematics Volunteers in Primary Schools) project was designed to address one of the key aims of the University of Manchester's Science and Engineering Education Research & Innovation Hub (SEERIH) – that of developing the links between university-based scientists and primary school teachers.

Primary science education plays a significant role in introducing scientific practices (including skills, body of knowledge, processes and relations) to children at an early age. The Wellcome Trust report (2015) finds that '*inspiring science teaching*' (p. 5) arises from strong leadership of science, with specialist teachers operating within a school model that allows evaluation and improvement of their practice. Specifically, collaboration between STEM ambassadors (such as research, professional scientists and engineers) and primary schools can enhance young children's experiences of science (NFER, 2011).

University outreach programmes have for many years harnessed the enthusiasm and interest of staff to share their passion and learning with the wider community. The key outcome of such work is often to enliven and enrich the school STEM curriculum, by providing a mechanism through which contemporary research and scientific processes can be shared within the wider community, potentially influencing the life choices



of young people (see Harrison & Shallcross, 2007). Building on this, SEERIH developed this project to foster collaboration between STEM volunteers and teachers, specifically with a remit to explore the ways in which to work with the primary age phase. The collaboration aimed to see the teacher-volunteer partners develop, deliver and review a learning experience together between STEM volunteers (business professionals, postgraduate or undergraduate students). The project sat within a programme of activity within SEERIH, framed by the Trajectory of Professional Development (Bianchi, 2016), which acts as a framework for the development of teacher leadership. This activity would be considered to act as a stimulus for 'collaboration', which Bianchi identifies as a development from teacher-volunteer participation. The defining aspect was the coming together of two areas of expertise to design and deliver an activity for youngsters.

Following an informal review of provision offered to STEM volunteers, it was noted that there is limited training for volunteers with regard to their particular roles within primary school science settings. Consequently, this project was developed to address the identified gap. The STEM VIPS project trialled a programme that was reviewed pre- and post-placement from a teacher and volunteer perspective. The aim was to enhance the quality and usefulness of the volunteering experience for all participants involved – volunteers, teachers and children.

This project sat within the landscape of STEM ambassadorial activity schemes, some of which are long-standing. STEMNET (The Science, Technology, Engineering and Mathematics Network) is an educational charity in the UK that seeks to encourage participation at school and college in science- and engineering-related subjects and (eventually) work. Its STEM Ambassador Scheme operates throughout the country and sits alongside university outreach and widening participation activity. Science-based charities and Learned Societies also offer schools similar support.

In a paper exploring the positive impact of outreach work on postgraduate students, Harrison *et al* (2011) argue that the benefits extend further still, including better understanding of one's own

subject knowledge – as the process of teaching challenges the subject matter comprehension of the teacher him/herself.

Therefore, the STEM VIPS project was designed to explore the impact of volunteers on the quality of science teaching and learning. *Thus, we asked the research question:*

- What are the processes that underpin successful collaborative STEM volunteer and teacher practices and with what consequences for children's learning?

Overview of the project

In this section, we first provide an overview of the project; how the participants were recruited and identified; the pre-placement stage and the role of the consultative group; and the structure of the STEM placements. This paper then focuses on the evaluation of the placements themselves.

Participants and recruitment

Two groups of practitioners were identified within the project: the Consultative Group (i.e. stakeholders) and the Placement Group (i.e. those who were actually partnered up for school visits). Detailed information of the participant representation is given in Appendix A.

The aim of the Consultative Group was to define the standards of high-quality primary ambassadorial experiences prior to the placements taking place. In comparison, the aim of the Placement Group was to partner a STEM volunteer with a particular primary school teacher in order to plan, deliver and evaluate an activity, workshop or lesson in the teacher's school. Thus, six teacher-volunteer partnerships were formed on the basis of the 'needs' of development of the primary schools, as well as the 'expertise' the STEM VIPS offered, as identified during the Consultative Group session. Placements took place over a 3-month timescale based on co-teaching practice (see Murphy, Scantlebury & Milne, 2015; Bianchi, 2016). The project team (two SEERIH staff) were responsible for setting up the Consultative Group, recruitment of STEM VIPS, developing and delivering the resources and any training for the STEM VIPS, whereas the evaluation/research team was tasked to critically observe all activities within this project and evaluate the placements (see Figure 1).

Table 1: Group of practitioners for the STEM VIPS project.

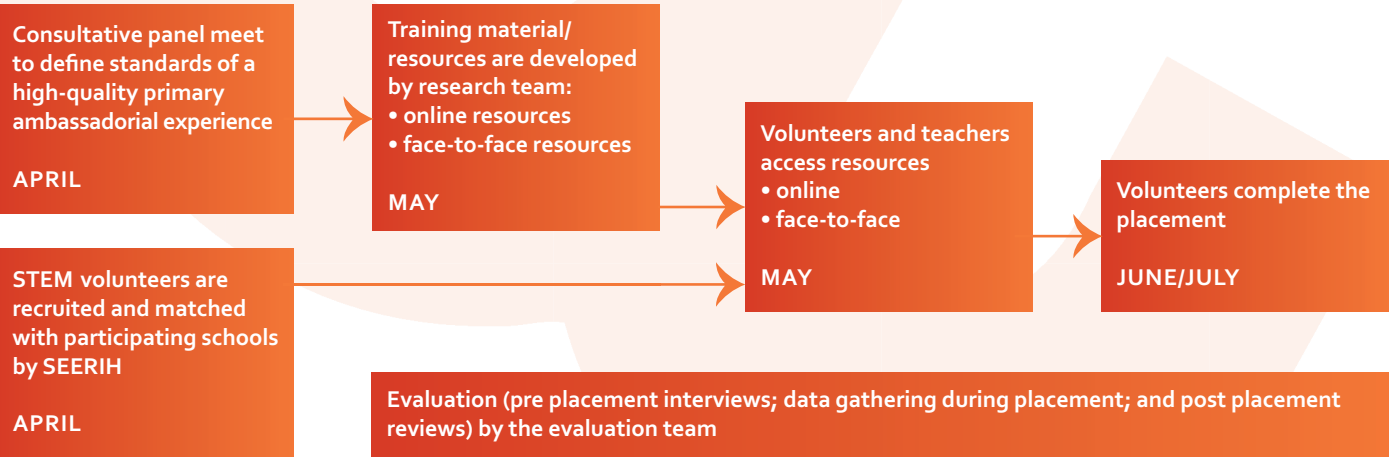
<p>The Consultative Group was formed from a variety of stakeholders operating in the world of primary outreach/school liaison, and included academics (with science and/or science education backgrounds), STEM Ambassadors (not the same as the STEM VIPS), primary teachers with STEM specialism roles in their schools (teachers who already have established links with SEERIH and are also part of the placement group) and leaders of educational programmes at the Museum of Science and Industry (MOSI).</p> <p>They met for a 4-hour workshop, with the key focus being to define the standards of high-quality primary ambassadorial experiences (April 2015).</p>	<p>The Placement Group included 6 mathematics and science teachers and 6 researchers recruited from schools associated with SEERIH, The University of Manchester and through the MOSI STEM Ambassadors network. From an open application process, six volunteers were selected such that there was a spread across the following factors:</p> <ul style="list-style-type: none">• previous experience of working with schools• academic discipline• student or business partner <p>They were matched into pairs and met up to six times. The meetings included the project developers and focused on finding out about the expectations of the project (April 2015); meeting placement partners (teacher-researcher groupings) (May 2015); interviews with a project researcher (May 2015); for the placements themselves (up to 2 visits during May-July 2015); and for group evaluation (September 2015).</p>
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STEM VIPS were also given the opportunity to attend a training workshop in which they were introduced to the resources provided by the project team (e.g. placement planning sheet, website with curricular links, etc.). The resources are available to view online at: www.primarySTEM.wordpress.com

Teachers and STEM VIPS were briefed about the resources and encouraged to access them online at their convenience. Some (up to half the volunteers) were also offered a face-to-face half-day meeting to review the resources as a group.

An overview of the development project plan, given below, illustrates the key stages in the project plan (see Figure 1). Similarly, the teachers had the opportunity to engage with the research team and elaborate on their expectations from these placements in a group activity, which led to the identification of their needs and the process of matching with a STEM VIP. Afterwards, teachers were invited to meet and organise the placements during a planning meeting, where they were introduced to the planning tool/sheet (see Appendix B).

Figure 1: Project plan overview.



Placements

A total of six placements were organised as part of this project, due to the complexity of the placements as well as the number of participants eventually recruited. Prior to the placement commencing, every participant was interviewed by the evaluation/research team (see Appendix C for an overview of activity ideas by the STEM VIPS).

Analysis

Data were collected by the evaluation/research team and analysed qualitatively by two means: (i) observational notes during the consultative group workshop to establish the overall features of a successful placement in the given context; and (ii) evaluative case study analysis (see Bassey, 1999) of the placements. The case study data collection from the placements involved interviews comprising questions focused on the teachers' and STEM VIPS' expectations from the school experience, and observational notes from the lesson activities, especially in terms of children's engagement with the various STEM tasks.

We report, firstly, on what the consultative group perceive as features of high-quality primary ambassadorial experiences, before evaluating two key case studies (placements 4 and 5 – see Table 2), in order to unpack the complex relationships between expectations and actual practices involved in a *successful* STEM-teacher placement. These two cases were selected on the basis of being exemplar and in contrast with each other.

Findings

Consultative Group

The Consultative Group discussion (formed of stakeholders – see Table 1) focused on identifying the features of a high-quality placement through group activities. Whilst a variety of views were shared, a set of common principles were identified:

- Fostering learners' curiosity should be valued highly within the placements by STEM VIPS as well as teachers;
- All placements will have flexibility to be different; there is not a 'one-size-fits-all' model;
- Placements should be well planned and well resourced;
- Placements should be about 'doing with' rather than 'doing to' the teacher/school/children;
- Placements should be related to the National Curriculum and should aim to broaden or extend it, providing opportunities beyond the curriculum; and
- Placements should leave some form of legacy, or generate some momentum for learning STEM, with schools, children and teachers.

In summary, the findings from the Consultative Group showed that placement models should be underpinned by an open-ended collaborative practice design framework, with potential for STEM learning that takes place to be creative, innovative and transferable. For example, in placement 4, we show that a collaborative practice design led to the engagement of children who otherwise were normally perceived as 'disruptive' by the teacher (more on this to follow in the following sections).

Table 2: Placement details – STEM VIPS Project.

Placement	STEM Volunteer	Teacher
1	David – computer science	Bethany – Year 6 (age 11) teacher
2	Kelly – PhD (cloud aerosol interactions)	Gary – Year 2 (age 7) teacher
3	Julia – medical doctor and PhD (intestinal health)	Maria – Year 2 teacher
4	Akash – PhD (mathematics / avalanches)	Jackie – Year 6 teacher
5	Ryan – PhD (stem cells and electrical stimulation)	Laura – Science Co-ordinator
6	Kelly – lecturer (dental material)	Lisa – Science Co-ordinator

Case study analysis

In this section, we present two case studies of contrasting placements for an in-depth overview, placement 4 and placement 5. These particular cases have been selected because they are exemplar and contrasting in terms of the remainder of the STEM volunteer activities in the five schools. Placement 4 presents a successful example of the STEM VIPS project through a collaborative approach; placement 5 highlights the significance of mediating resources to facilitate the process. Before a brief overview of each placement, we list some of the expectations of both sets of participants prior to the placements:

STEM teachers' expectations prior to the placement

STEM teachers' expectations regarding the volunteers were varied according to the teachers' previous experience of working with STEM volunteers:

- **New ideas** (e.g. science knowledge or skills) and possible curricular links. For example, Gary (a Year 2 teacher new to his school science specialist role) expressed an interest in his own professional development; talking about visiting volunteers, he says: *'they'll come in with fresh ideas and in the long term it'll help me because I can take their ideas and use them next year'* (pre-placement interview). Gary also highlighted their contribution to new ideas to implement the new curriculum: *'they're going to come in and help me to look at science...in an alternate way'* (pre-placement interview).

Gary suggested how they contributed to *'more practical lessons'* (and forming links between what is being learned at school and *'how it actually exists in the real world and where the jobs are and the aspiration and the sort of... future sort of planning for what they might do in careers'* (Bethany, see Appendix A)).

- **Transferable skills** developed through workshops. Lisa (an experienced science co-ordinator) discussed the transferability of skills through specific kinds of workshops that emerged out of the placement. She indicated that: *'this workshop could be used in all schools... and [to] get more scientists into school everywhere'* (pre-placement interview). So, Lisa's expectations (compared to Gary's) are more general in that they are related to

something from which all schools could benefit. The focus here appears to be on creating a legacy in the form of a transferable skills workshop.

- **Role expectations.** Most teachers expected volunteers to lead developments of the big ideas, anticipating that they would support in helping to *'pitch the 'big ideas into small achievable areas of knowledge for the children to grasp'* (Laura, pre-placement interview), and also provide some behaviour management. Gary, however, remained more open-minded about who would do what at the pre-placement stage.

STEM volunteers' expectations prior to their school placement

In contrast to the teachers, the volunteers held quite different notions about the ways in which they saw themselves contributing to the programme.

- **Ideas and resources.** All volunteers had ideas and resources that they had already planned to bring to the placement (for example, Akash brought a Perspex simulation of an avalanche available to share; Julia talked about her research looking at intestinal health; Sam had developed a tour of the cloud chamber at her department; etc.); with the exception of Kelly who saw her role as assisting rather than leading the session: *'If there is a workshop already organised I think I'll probably be more going to be on the facilitating and supporting role'*.
- **Role expectations.** Additionally (similar to the STEM teachers' expectations), STEM volunteers also expected to be helped with *'managing the children'* and knowing *'their [teachers'] aims in terms of the curriculum'* (Ryan, see Table 2), especially in terms of helping them to plan the activity: *'I can have loads of crazy ideas but actually the kids are just not going to get it. The teachers obviously know that, so yeah, more experience from the teachers in that respect'* (Kelly, see Table 2). However, most of the STEM volunteers did not expect to lead the sessions by themselves. There appeared to be an expectation of working more collaboratively with the teacher around the ideas that they had.

In the following sections, we take a closer look at two cases (of STEM volunteer experiences) to

provide an overview of the actual events during the placements, and also to see how the expectations impacted on the actual activities (i.e. workshops/ lessons/ presentations, etc.) that took place in the schools. Placements 4 and 5 (see Table 2) were chosen to elaborate upon, because these involved the most contrast in terms of how the placement was planned between the volunteer and the teacher, and then actually conducted, compared to the initial STEM teacher/volunteer expectations. Where necessary, additional information from other placements is included to support relevant discussions related to the project.

Case 4 (Akash and Jackie)

For Akash and Jackie (see Table 2), the expectations of their relationship prior to meeting were significantly different. Jackie (the Year 6 teacher) was keener on taking a 'back seat' to handle pitch and behaviour management when required. Whereas Akash expected a greater input from the teacher in terms of delivering his idea of designing a workshop around his avalanche Perspex model.

The placement itself was conducted in one morning session with a class of 25 (Year 6) children. Jackie and Akash first met during the official teacher-volunteer meet-and-greet meeting, where

they were handed the planning sheets in order to organise and plan for their upcoming placement (see Table 3).

The main 'activity [itself] was based around solving a real life problem about predicting the flow of particles during an avalanche. The children were told that they had to find a safe place for the Lego woman by using their knowledge of angles and shape. Children learnt about how to apply their knowledge of maths to wider situations but also an insight into what an avalanche is and why they happen' (Jackie, Year 6 teacher, post-evaluation).

The resources/tools used/required for this placement were:

1. Avalanche Perspex model x 6
2. Video of Lego man
3. Images of particles/flow of avalanche
4. Particle separator simulation equipment
5. Objects made out of various shapes
6. Wood planks
7. Lesson presentation

Akash was responsible (with the help of his department) for arranging the avalanche Perspex models, providing images and the creation of the

Table 3: Lesson activities for case 1.

Activity	Resources	Learning objective
Starter – angles and shapes	PowerPoint	To recap angles and shapes
Lego avalanche activity	Avalanche Perspex Avalanche video Pictures of rocks – visual representation	To understand that different shapes of rocks and objects roll down the hill at different speeds.
Group activity – Rolling shapes	6 x 1/2 metres MDF and different shapes	To understand that different shapes of rocks and objects roll down the MDF at different speeds.
Group discussion	Discussion in relation to original question and video – putting that all together	To understand angle of slope – with the models again To consolidate – why does it move in this pattern?
Consolidation activity	Posters	Kids to produce pic – collage

video. Jackie, however, took a lead in organising items 5 to 7. The lesson presentation itself was finalised just prior to the commencement of the actual activities.

The lesson started with Jackie leading on introducing the objectives and starter (checking children's understanding of angles and shapes). What transpired, however, was that both Jackie and Akash alternated in taking the lead throughout the entire session and at times added to each other's lead contributions. As such, during the actual activity (as well as in the initial planning stages), both were working collaboratively,

Case 5 (Ryan and Laura)

Similarly to Jackie and Akash, Ryan met Laura during the first planning meeting, where it was decided that the placement (see Table 2) would take place over three sessions. Ryan himself described the sessions (post-evaluation), starting with the first:

'Virtual Lab tour via Skype: As a way of introducing myself, I gave the kids a virtual tour of our laboratory, explained some of the work that we do and a demonstration of liquid nitrogen. [I] worked with both Year 5 (age 10) classes separately [with a] workshop, 'think like a scientist'. [I] introduced what a scientist is; what experiments are. I performed some benchtop demonstrations with phenomena that the kids wouldn't necessarily be able to explain and got them to try and explain it. Also worked on two big problems in modern society: ageing population and global warming – presented the kids with a fact, i.e. the percentage of the population over 65 is increasing in the UK, and got them to think about potential problems and solutions – the idea being to get the kids thinking independently. We also had an "ask a scientist" Q+A session which pretty much covered everything.'

He described the second session, which was an engineering challenge for all of Year 6, highlighting how they *'discussed what engineering was and the basics of bridge design. Groups of five were given a bag of materials – paper, straws, lollipop sticks, etc. and asked to build a bridge spanning a 30cm gap... Bridges were then tested to failure using bottles of water as a weight. Some of the teams produced bridges able to withstand 4 kg of load!'* (Ryan, post-evaluation).

No further joint planning activities happened after the very first session, except for arranging dates and times for the visits by Ryan. Ryan worked out the details of each of the activities with the help of the resources provided by the project team. He explained how this worked:

'The majority of the planning was done in the initial contact meeting, at which point the planning sheet was very useful. After that some further details (timings etc.) were thrashed out via e-mail. The website sections on communicating with primary students and the syllabi were very useful as they helped me to plan the activities (in particular what level to pitch things at – where things would be understandable but challenging). I did not use any of the website resources after the first activity...' (Ryan, post-evaluation).

As it happened, Laura (the science co-ordinator, see Table 2) was not able to join in with any of the sessions, especially since they were organised with different class year groups. No direct communication took place between the individual class teachers and Ryan. One member of the evaluation/research team had the opportunity to join Ryan during the session in which the children were asked to build bridges out of materials provided. About 60 children (the entire Year 6 cohort) were asked to sit in the assembly hall, where Ryan was asked to set up. The concept of bridges was first introduced through a presentation with visual stimulations, before the task of building their own bridges was introduced. Several staff members (class teachers and teaching assistants) were present during this session, primarily for behaviour management. The children, though initially unsure, eventually found the confidence to just try and attempt it (as noted by one of the teachers assisting with the activities). Due to the size of the hall and the number of children, it was slightly more challenging to make this session interactive during the first half and, later on, to ensure that every child was engaging with the task. Towards the end, nearly every group had the opportunity to test their bridges across the gap between two tables (in terms of how much weight they could hold before they collapsed – also noted by the teachers assisting with the activity, as well as by the researchers).

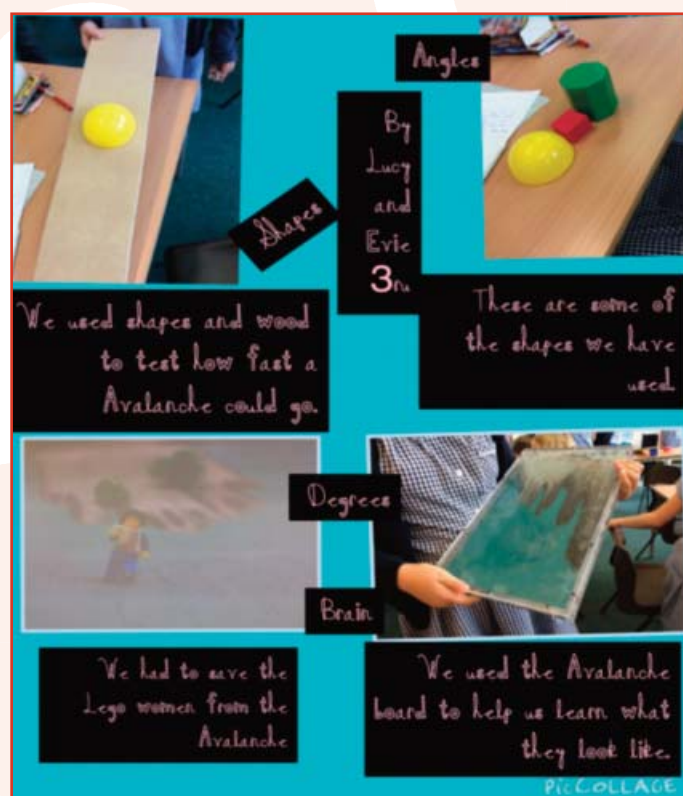
What did we learn about STEM volunteer placements?

Strengths

● Impact on children

In both cases, impact on pupil engagement/enthusiasm was noted by both researchers and teachers. For example, in case 1, the children were able to consolidate their learning with a follow-up activity led by Jackie only (after we had left – see Figure 2). There was plenty of evidence that the children were engaged in the lesson – especially those who were seen to struggle with mathematics (as identified by the teacher): *'This is cool maths. This is clever maths'* (female student identified as 'struggling' by the teacher). Some children (who were identified by the teacher as low-ability) also went on to present their findings from the lesson to another Year 5 class and the Headteacher.

Figure 2: STEM posters created by children – case 1.



In placement 5, the first activity was a success with the children as Laura noted: *'The children loved it and were buzzing with excitement afterwards. Before the session 10/61 had thought about science as a career; afterwards that number rose to 48/61'* (e-mail feedback). The enthusiasm of the children was also notable towards the end of the third activity.

● STEM teacher and volunteer collaboration

In placement 4, two critical moments (which the researchers perceived facilitated children's learning) were identified: (i) Akash obtaining resources that were interesting and demonstrated visibly the principles he was trying to convey (pedagogic content knowledge at work) – the Perspex simulations that modelled the flow of an avalanche and a video that he created to pose the problem to be solved: how to save Lego woman from the avalanche? He also then supplied images with which they were able to interact on their iPads – which Jackie was very good at getting them to do as a class, and (ii) Jackie's enthusiasm and understanding of what Akash was modelling, which meant that she did quite a bit of the actual teaching. The children needed mediation in relation to the understanding of the process of the avalanche flow as demonstrated by Akash, which Jackie provided. Although the actual activity was planned within one meeting, the success of the delivery of the concept was rooted in Akash's ease of delivery of highly mathematical concepts to non-mathematicians and, specifically, children. Interestingly, Akash noted that he had *'kind of like grown up around teaching'* (pre-placement interview), as his mother is also a teacher, which may explain the way in which he developed the resources to make his post-doctoral research accessible. Additionally, Akash had previous experience of carrying out similar demonstrations during, for instance, a Big Bang Science Fair.

At the same time, in placement 5, Ryan emphasised that (for a successful placement) it was key for the dialogue (in terms of planning) to take place between the actual class teacher and the volunteer: *'It would have been helpful to have been in initial contact with the actual class teachers rather than the co-ordinator – the teachers knew I was coming but not the exact details of what I was doing'* (Ryan, post-evaluation). This was reaffirmed by Laura: *'I think clear communication and expectations from both parties are key'* (post-evaluation) in terms of what makes a good ambassador placement. In fact, communication was picked up by Ryan as a necessary requirement for a successful STEM ambassador placement.

● Background pedagogical knowledge

An understanding of the education system and pedagogic culture also appeared to be important

in facilitating the successful development of collaborative practices from pre-participation to participation in the placements (see Bianchi, 2016) and noted with regard to Akash's familiarity with this, mentioned earlier. In placement 4, Jackie didn't expect to be involved much with the actual sessions prior to meeting Akash. However, as soon as they met, they were quite clear about what they wanted to do from the outset. This was because Akash had done similar activities in other contexts (e.g. Big Bang Science Fair) and Jackie was very confident about how her class would deal with these activities. Jackie appeared to really understand the basic principles behind the activity, because it was made accessible by Akash (via his prior experience). Similarly, Jackie and Akash stated that *'none of the provided resources were really utilised, and the website [was not used]'* (Akash, post-evaluation). Thus, Akash and Jackie were very much a double act and, in fact, the behaviour management practices dropped off the radar as the lesson progressed since all became engaged in what was being taught. Thus they started co-creating.

In another example, Lisa (science co-ordinator from placement 6) noted that key to a good placement is *'enthusiastic teachers and ambassadors working together to create experiences that enrich the curriculum for the children, that the teacher could not facilitate on their own'* (post-evaluation).

- **Use of STEM volunteers' own resources**

In another placement (3), key resources were used (similar to placements 4 and 5) to engage children throughout the activities. These included practical

interactive elements as much as demonstrations by Julia (STEM volunteer). For example, children were shown a toy model of the length of the intestine, which they were able to stretch out (see Figure 3), and this was followed up by a video of parasites in the gut. Straight afterwards, children had the opportunity to stick their hands into buckets full of jelly in order to find the hidden toy worms. Children were also able to learn about the different parasites found in the gut. Every demonstration or activity was followed by a question-and-answer session 'on the carpet'. However, Sam (teacher) noted that *'children [should be] sat on the carpet less'* (post-evaluation), which shows that there was potentially an expectation in relation to the pedagogical underpinnings of such an activity. Interestingly, various parts of the sessions were led by Julia in their entirety, whereas Sam was mainly involved with behaviour management.

Challenges

Where the organisation of the placement was undertaken by the science subject leader on behalf of other staff in the school, or if any stage of the collaborative working (co-planning, co-practice or co-review – see Bianchi, 2016) was limited due to pressures of time or location, the depth of impact on those taking part was more variable for all parties – the STEM volunteer, teacher and children.

- **Mediation of activity: planning sheet/website/dialogue/etc.**

Some of the teachers and STEM volunteers did not use the planning sheet/ resources at all. For instance, Gary and Kelly (placement 2) turned over the planning sheet and made their own notes during the initial planning meeting in order to

Figure 3: Volunteer objects: intestinal germs, intestine model and teeth model.



prepare for the placement (as did Akash and Jackie). When asked why they had done so, they indicated that it was more important to 'talk about' the ideas and the delivery of the ideas than fill in the sheet.

Whereas, in placement 5, it was not possible to evaluate the impact of the expectation of the teacher-volunteer relationship on how their role was conducted, as Laura was not present during the sessions and communication between actual class teachers and Ryan was not established. However, this is not to say that the placement was not a success. On the other hand, what resulted was that, in this case, it is possible that the planning tool stimulated the dialogue during the initial planning meeting. Later on, perhaps, it became a focus, since the dialogue could not happen without the presence of the actual teacher (rather than co-ordinator). In comparison, the two cases mentioned previously (Akash/Jackie and Gary/Kelly) illustrated very clear ideas about what they were doing from the outset and, hence, the tools were not felt to be needed.

The joint planning of the activity has also been identified as a critical moment during the placement where expectations of the volunteers and teachers could potentially shift. For example, whereas Gary (placement 2) was more hesitant in the beginning in terms of expectations from the volunteers, he *collaboratively* delivered a series of activities with Kelly around her ideas and resources. Key in terms of planning was meeting '*in person to establish a good working relationship*' (Bethany, post-evaluation) between the STEM volunteer and teacher to ensure a successful placement.

In summary, it can be argued that resources such as the planning sheet and website mediated the planning of the activities and placements, but key to a successful outcome was dialogue, and the nature of that dialogue, between the actual class teacher and the STEM volunteer (who had become more of a science ambassador as the project unfolded).

Discussion and conclusion

In conclusion, the more detailed description of placements 4 and 5 worked in quite different ways: (i) the STEM volunteer-teacher relationship and (ii)

the activity that arises from that relationship. The activity itself is mediated (to varying degrees) by the dialogue between the STEM volunteer and teacher, and the resources provided, i.e. planning tools, curricular links, etc., by the project team; STEM volunteers' repertoire (ideas and use of objects); and teachers' repertoire (e.g. pedagogical content). Thus, this paper critically questions the means and style of facilitation to be considered by educators to support the development of collaborative practices between STEM volunteers and teachers for meaningful learning experiences for children.

Hence, we can see that the extent to which any of the resources provided by the project team are implemented appears to depend on the understanding between the STEM volunteer and teacher, the volunteer's pedagogic content knowledge and prior experience, and their ability, and (maybe even more so) opportunity to communicate and plan around their ideas directly with the teachers prior to the sessions. Ideas and unique artefacts (which are outside the scope of a teacher – who does not necessarily consider him/herself a 'scientist' – or are just not available in the schools) are also valued, not only by the teachers, but also by children, who get to experience science in a different 'light'.

Similarly, more opportunities to meet (either face-to-face or virtually) more than once also appear essential to ensure that the professional and pedagogic dialogue continues and that the relationship is secured prior to the actual session. As in the case of Jackie and Akash, good communication with clear expectations on both sides resulted in a collaboratively-led session that appeared to enhance children's enthusiasm in mathematics, especially in the way they perceived mathematics in real life.

This paper, therefore, suggests that STEM volunteer placements require a structured programme of support, be it face-to-face or online, the focus of which is to facilitate and broker the relationship between STEM volunteers and teachers through dialogue, co-planning and co-review. Where co-teaching is happening in current programmes, it was found that enhanced opportunities to share learning and understanding were of value to all participants in differing ways.

Thus, based on the Trajectory Model of Professional Development (see Bianchi, 2016), the STEM VIPS project was a means by which to encourage volunteers to begin to collaborate with teachers in primary schools – in essence, they were on their own trajectory of professional development, moving from 'participate' to 'collaborate'. Arguably, the mediation by the project and research teams – e.g. through the provision of resources, the mentoring/support frameworks, etc. – were all developed to facilitate them on their journey towards 'collaboration' – a sharing of professional expertise by working together. Our ongoing challenge as STEM educators is to explore how we can share expertise across professions and capitalise on teacher pedagogical expertise, together with more expert scientists. In the STEM education sector, it is suggested that, all too often, teacher expertise is dismissed or undervalued and opportunities need to be created that enhance shared collaboration to provide enriched science experiences for children.

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No boundaries, No barriers: the PSTT International Primary Science Conference, Belfast, June 2016



Appendix A: List of members of consultative and placement groups

Consultative Group	Placement Group
Project Developer and Engineering Champion, SEERIH, The University of Manchester.	Primary school teacher and Computing Leader
Head of the SEERIH, The University of Manchester.	Primary school teacher and Maths Leader
Head of Learning and Public Programmes, MOSI	Primary school teacher and Maths Leader
Project Researcher Research Associate in School of Environment, Education and Development at The University of Manchester.	Primary school teacher and Science Leader
Widening Participation Officer at The University of Manchester.	Primary school teacher and Science Leader
Research Associate - School of Earth, Atmospheric and Environmental Sciences	Primary school teacher
Professor of Atmospheric Chemistry at The University of Manchester	Retired teacher of DT and computer science
Senior Lecturer in the School of Computer Science at The University of Manchester.	3rd Year PhD Student. School of Mathematics, The University of Manchester.
Senior Lecturer in School of Environment, Education and Development at The University of Manchester.	Postgraduate at The University of Manchester, Faculty of Life Sciences
Primary school teacher and Computing Leader	PhD Student in Centre for Doctoral Training in Regenerative Medicine, The University of Manchester.
Primary school teacher and Maths Leader	Lecturer in Biomaterials Science, The University of Manchester.
Primary school teacher and Maths Leader	Postgraduate student in Centre for Atmospheric Science
Primary school teacher and Science Leader	
Primary school teacher and Science Leader	
Primary school teacher	
STEM Ambassador	



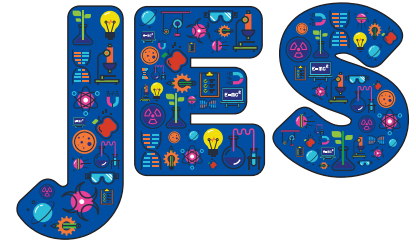
NAME(S): School where the placement will be held:	DATE:
KEY OBJECTIVES OF THE PLACEMENT (tick the relevant points)	YOUR NOTES
Increase pupils' curiosity in STEM Sharing STEM volunteer's research/job/expertise with pupils Enriching/enhancing delivery of the National Curriculum Raising awareness of STEM careers & showing what a real scientist/computer scientist/mathematician looks like Raising profile of STEM across school Enhancing teachers' subject knowledge	
PLACEMENT ORGANISATION When will the placement take place? How many visits? Duration of visits?	
What will take place before the placement to maximise impact? How will pupils be involved in organising the placement? What work will pupils do before the placement (e.g. developing questions, learning about specific topics)?	
PUPILS One class or many? One year group or many? Working with individual pupils/small groups/whole class? Are there any specific groups to target? (E.g. girls in science) What is the preference of teacher and volunteer and why?	
LOCATION Where is the best place for the placement to take place? (classroom, hall, school grounds, off-site, high school)	
Why?	

TECHNOLOGY What technology is available? Interactive Whiteboard (SMART or Promethean)	
Internet Access – yes, no. Have you got the access codes?	
Laptops and computers for pupils	
iPads or other tablets	
Other	
RESOURCES What resources are available in school to support the placement?	
What resources could the STEM volunteer bring along?	
Are there organisations that loan equipment which may support the placement?	
Staff resources – Do any arrangements, e.g. extra support staff, need to be recruited for this activity? E.g. Teaching Assistants, parents etc.	
Transport – will transport off site be required?	
BEHAVIOUR What behaviour management systems are in place? How can the STEM volunteer use these?	
PLACEMENT IMPACT – LEGACY What will happen after the placement? What impact do you expect this to have?	
EVALUATION How will the effectiveness of the placement be measured?	
From perspective of teacher/volunteer/pupil?	
OTHER INFORMATION e.g. timings of school day, STEM volunteer dress code, issues around working with groups of children independently or with supervision, name of Headteacher, parking facilities, lunch arrangements.	

Appendix C: Overview of STEM VIPS ideas for placement activities

Placement	STEM Volunteer	Ideas
1	David – computer science	'To the basics of how a computer works' with programming.
2	Kelly – PhD (cloud aerosol interactions)	'A workshop that we can take to a school... with clouds. We make clouds and we show why aerosols are important to making clouds and there's other stuff. There's one about acids in the atmosphere, one about counting particles in the atmosphere...'
3	Julia – medical doctor and PhD (intestinal health)	'To intestinal health issues with practical hands-on activities with children'.
4	Akash – PhD (mathematics / avalanches)	'To bring in a mathematics avalanche demonstration and design the activity around it'.
5	Ryan – PhD (stem cells and electrical stimulation)	'Interactive demonstration-type workshops or even just trying to tell them just what life is like as a scientist'.
6	Kelly – lecturer (dental material)	Activities on dental hygiene.

Exploring the use of inquiry-based science pedagogies across primary-secondary transition: How does the literature relate this to the declining uptake of science in secondary schools?



● Sally Howard

Abstract

The number of students choosing not to continue with science beyond compulsory age remains a concern for teachers and potential employers, not just in terms of a diminishing pool of budding scientists, but also the potential lack of scientific literacy in tomorrow's population. A lack of engagement and poor science identity is being associated with the way in which the subject is taught at primary and secondary school level, rather than a disengagement with the discipline itself. In 2007, the Rocard report stated that inquiry-based science education (IBSE) is more relevant and engaging for pupils than traditional didactic approaches. This is because the methodology develops the skills and practices associated with the way that professional scientists work, promotes the role of collaboration between peers and is highly motivating for teachers and learners. This more authentic approach to understanding science and working scientifically is thought likely to encourage more pupils, including girls and under-represented minority groups, to engage with scientific subject matter in a positive way for longer.

Keywords: Inquiry; transition; engagement; attitudes; science process; science pedagogy; primary science

Introduction

It is well argued (Archer *et al*, 2010; CBI report, 2015; DeWitt, 2015; Harlen & Qualter, 2014; Murphy & Beggs, 2003; Osborne *et al*, 2003) that pupils' understanding about science, what it means to be a scientist and how this relates to them as individuals is formed early in a child's schooling and not just during the secondary phase of education. It is also recognised that interest in science itself appears to remain relatively high throughout compulsory schooling, yet attitudes towards science lessons in school seem to begin to decline

well before the age of 11, and probably around the age of 8 years (Murphy & Beggs, 2003; Turner & Ireson, 2010; Potvin & Hasni, 2014), with a further more rapid decline between the ages of 10 and 14 years (DeWitt *et al*, 2015). This seems to be linked to it being perceived as a difficult subject, or not relevant to their lives. This is an ongoing cause for concern, as poor attitudes and disengagement are believed to contribute to the diminishing uptake of science subjects post-compulsory stages of education, along with the development of pupils' poor science identities and believing that science is 'not for me' (Archer *et al*, 2010 p.20; CBI report, 2015 p.12), with a corresponding adverse impact on scientific literacy in tomorrow's population of citizens. The decline in students' interest in school science, therefore, appears to be exacerbated during (and after) the time of transition from primary to secondary education.

Miner *et al* (2009, p.3) state that science inquiry has figured prominently in science education for some time and consists of three key aspects that are inter-related:

- what scientists do (e.g. conducting investigations using scientific methods);
- how students learn (e.g. actively inquiring, through thinking and doing, into a phenomenon or problem, often mirroring the processes used by professional scientists); and
- a pedagogical approach that teachers employ (e.g. designing and using curricula that allow for extended investigations with greater autonomy given to the learners to make decisions).

She goes on to report that, regardless of who is doing the inquiry, the act itself has some general core components, including learners' active engagement and the use of evidence to draw conclusions. While there is generally agreement regarding what pupils should be learning about,



there is much less understanding about the teachers' roles and how they should best instruct their learners, including deciding how much opportunity should be afforded to the learners to decide the direction of the inquiry.

Recognising that some primary teachers may not be science specialists or have a science qualification, yet all secondary teachers will possess a degree in science, there may be significant differences in the way science and inquiry are understood and developed in these two phases of schooling. Miner's study identifying 'what scientists do', as an important part of inquiry, may then be perceived differently by a primary teacher compared to a secondary science teacher.

It is generally thought that, through the process of inquiry, better understanding of the world will evolve by taking a developmental and tentative approach, which will include pupils taking wrong turns and going up blind alleys (Harlen & Qualter, 2014, pp.92-95; Abrams *et al*, 2008, p.135) and learning through practical hands-on activities. Ofsted, in their report *Maintaining curiosity* (2013), highlighted that the best schools ensure that pupils' understanding of the big ideas of science and mastery of investigative and practical skills is through inquiry-based approaches, where pupils are fully involved in planning, carrying out and evaluating investigations, and making decisions about the direction the inquiry process might take (p.5-11). However, for teachers to truly appreciate more authentic ways of nurturing inquiry skills, they need to appreciate how to provide their learners with 'real' opportunities to do so.

Recognising where the locus of control lies has led to inquiry being defined into three broad categories: 'open inquiry' (where all the key decisions will be made by the learners); 'guided inquiry' (where the teacher will decide which choices learners can take), and 'closed inquiry' (where the locus of control is firmly with the teacher who directs the whole process). Closed inquiries, where experiments have been carried out following a set of instructions, have been a common form of inquiry, particularly within a secondary school setting (Harrison, 2014, p.115) and, while they are of value in terms of confirming a known outcome, they are limited in terms of enabling the development of key competences and

skills necessary for a high degree of scientific literacy (Ofsted, 2011 pp.11-14; Science & Learning Expert Group, 2010, pp.57-58).

Disengagement with science education

For some time now, science has been perceived as 'masculine' in nature, especially in terms of the physical sciences, and this has been linked to the way it is taught (Rocard, 2007; Osborne *et al*, 2003, 2009). A traditional didactic approach is often a feature of secondary science lessons, where inquiry is represented by highly orchestrated practical experiments. This approach is also present in some primary schools, with an over-dominance of 'fair testing' (Ofsted, 2011, 2013), with the teacher always taking control over the direction of what is done and how. These didactic approaches by their very nature have alienated certain groups of learners, such as girls and some minority groups (Rocard, 2007). While it is not being argued that open inquiries should be the only form of investigation, inquiry-based pedagogies have been found to be more engaging, inclusive and effective (e.g. Crawford, 2014; Fibonacci project, 2010-2013; Rocard, 2007; Wilson *et al*, 2010), with a cumulative positive effect, meaning that the more inquiry pedagogies are used, the more proficient the learners become, resulting in better learning gains (Furtak *et al*, 2012).

A key factor for teachers to recognise is the way that inquiry-based pedagogies can be designed to build on a child's natural curiosity and foster creative and critical reasoning skills. The very nature of an 'open' or 'guided' inquiry process requires learners to draw on their current understanding to help them make numerous decisions about what to do, how to do it and then evaluate the evidence they have collected. A variety of decision-making processes are inherent in inquiries, which echo the way in which professional scientists work, including working collaboratively, raising questions to which they want to find answers, making choices about equipment and how to conduct the investigation, as well as drawing conclusions from their evidence. This kind of open approach generally shifts the locus of control away from the teacher towards the pupils. Miner (2009, p.14) notes that, by using authentic contexts, experimental knowledge can develop alongside theoretical knowledge. The

authentic nature of IBSE pedagogy is believed to translate into better engagement and motivation, alongside the learning about science and science knowledge (Rocard, 2007).

The much-quoted Rocard report, *Science now: A renewed pedagogy for the future of Europe* (2007), also clearly states that the way to address the issues related to the way that science is taught in primary and secondary schools is by changing teachers' pedagogy towards a greater emphasis on IBSE. Working in a way similar to professional scientists, where collaboration, investigation and reasoning from the evidence is advocated, would not only enhance pupils' understanding of science, but also their appreciation of how scientific knowledge develops. This, it suggests, would improve pupil motivation and enjoyment and address imbalances in the way that science education is experienced by different learners (Hmelo-Silver *et al*, 2007; Wilson *et al*, 2010; Rocard, 2007). Scientific literacy and positive attitudes to science are then more likely to develop

in both formal and informal arenas, which would, amongst other things, help increase the interest of girls in science:

'...initiatives in which IBSE approaches are being used, girls participate more enthusiastically in the activities and develop a better level of self-confidence than with the traditional approaches to teaching science' (Rocard, 2007, p.19).

Inquiry-based pedagogy is not a simple recipe to follow, but a complex process that teachers and learners need time and support to fully understand and translate into their practice. In an attempt to unravel some of these complexities, the Primas Project (Promoting Inquiry in Mathematics and Science education across Europe) outlines a simplistic comparative model (for primary and secondary teachers), by describing the actions of two types of teachers: Mr. Shaw represents the traditional didactic teaching approach and Mr. Hammond an inquiry-based teaching approach (Primas Project, 2013, p.7):

MR. SHAW'S LESSON	MR. HAMMOND'S LESSON
The teacher poses the questions that are to be explored.	The teacher introduces a stimulus to the class and invites students to observe, describe and pose questions. He awakens curiosity.
The teacher gives each pair of students the equipment they will need.	The students are allowed to select the equipment they need.
There is no room for predicting and testing. Possible mistakes and misconceptions are avoided.	Predictions are discussed and tested. For example, students assume that the relationship between the length of a pendulum and time is linear, and test this.
The task is completely structured by the textbook. Students make very few decisions. They mainly follow instructions.	Students are allowed to tackle the problem in any way they wish. For example, they are allowed to use trial and error. They make decisions for themselves.
The teacher tells students to check their work for accuracy.	The students check each other's work for accuracy.
The teacher mainly instructs and gives information and evaluates work.	The teacher challenges, questions and provokes students to think for themselves. Students present and evaluate each other's work.

While inquiry pedagogy can be conceptualised in terms of the degree of autonomy afforded to the learner, and ranges from 'teacher-directed' as in a closed inquiry, through 'teacher-guided' and, at the other end of the spectrum, is an open inquiry that is 'student-led', there are also different types of inquiry approaches based on the focus of the learning intentions, which the teacher needs to consider when planning an inquiry based experience.

These three aspects to inquiry indicate the focus of learning:

- Learning *through inquiry*, where conceptual understanding of the big ideas in science are scaffolded;
- Learning *about inquiry*, where the focus is on developing understanding of specific inquiry skills within a science concept and authentic problem-solving scenario; and
- *Doing an inquiry*, where the focus is on replicating a method to achieve the same outcome. Here, the teacher makes the decisions and this is probably the most common form of inquiry in schools.

Each of these three approaches require differing teacher pedagogical practice, depending on the focus for the learning. All three have their place, although there is a strong argument to increase the use of the first two compared to the third. While 'doing an inquiry' might include hands-on practical experiments, there is no opportunity given to the learners to make choices such as raising their own questions, deciding on the equipment, the data to collect, the means by which to collect them, and how to report evidence, let alone critique each other's work, including their analysis and conclusions. It is this limited chance for learners to take greater autonomy over the direction of their investigation that can inhibit both positive attitudes towards science education and more effective learning.

The emphasis on the active engagement of the learner and their role in decision-making is clearly captured in the definition of inquiry that the Strategies for Assessment of Inquiry Learning in Science project (SAILS, 2016) used when drawing on the work of Linn, Davis and Bell (2004, cited in SAILS' final report, 2016), stating that inquiry-based pedagogy is the:

'intentional process of providing opportunities where students are actively involved in diagnosing problems, critiquing experiments and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments'.

How well embedded is inquiry-based pedagogy in teachers' practice?

Despite inquiry-based science teaching having been advocated for some considerable time, by many in Europe and other continents (Crawford, 2007; EU Commission, 2015; Rocard, 2007; Wellcome, 2011; Wilson *et al*, 2010), it remains under-represented in most teachers' practice (Crawford, 2014; Ofsted, 2015). The difficulties seem to be associated with how inquiry is conceptualised and enacted by teachers. The confusion about IBSE is not merely caused through the differences in spelling, where the UK spells it 'enquiry' while the rest of Europe and others, including America, Australia and New Zealand, spell it 'inquiry', but also hinges on the lack of a unified definition and lack of teacher confidence or understanding about how to implement it within their prescribed curriculum (Furtak *et al*, 2012).

It also needs to be recognised that there are some strong disagreements about the claims of inquiry-based pedagogies, which likewise seem to stem from the confusion over terminology and the variety of practice within IBSE. While Abraham and Millar (2008, pp.9-10) found that teachers often missed relevant opportunities to develop understanding of scientific inquiry, (including not drawing pupils' attention to such things as the relevance or the quality of the evidence they used, but tending to focus on using inquiry to develop science knowledge), their research does not support the claim that inquiry-based science is ineffective as suggested by Zhang (2016), but actually draws attention to the complexities and challenges involved in effective inquiry pedagogy. This tends to support the argument that teachers require sustained professional development (Crawford, 2014, p.516; Dunne & Peacock, 2012, pp.185-188) for them to understand and apply extended and more open-ended student-directed investigative tasks effectively.

However, there are two contrasting views about the worthiness of IBSE, and the fundamental tension is around the degree of guidance and instruction afforded to the learners during the teaching (Zhang, 2016, pp.10-12). A consensus by the critics is that teachers employing an inquiry practice withhold solutions in order that the pupils learn solely through practical exploration and discovery (Kirschner *et al*, 2006). Further arguments include views that, through 'discovery learning', 'inquiry learning' and 'problem-based learning', the working memory capacity is overloaded and this hinders knowledge acquisition, which is frustrating for the learners and generally a poor use of time (Kirschner *et al*, 2006; Mayer, 2004; Sweller *et al*, 2007). These critics argue fiercely that direct instruction with the giving of solutions is by far the most effective way for a learner to understand key procedures and gain knowledge of concepts. They go on to say that the role of practical experimentation is then best used for verification of known phenomena. They conclude that a didactic approach, where instruction from the teacher includes solutions to problems, is a more efficient and effective way to know and understand science and the scientific method, which does not result in cognitive overload.

On the other hand, advocates of IBSE provide strong counter-arguments, stating that the teacher does not withhold guidance or instruction, but carefully ensures that scaffolding of learning is embedded within their practice and involves a range of strategies, such as timely and skillful intervention by the teacher (Hmelo-Silver *et al*, 2007, p.102), as well as collaboration between peers. Both assist the learners in making meaning through their discussions and actions (see, for example, the following projects: Fibonacci, 2010-2013; PRIMAS, 2013; SAILS, 2016). There is a consensus that achieving an effective inquiry-based pedagogy does require time and effort on behalf of the teacher and their learners (Yeomans, 2006, p.3), and often teachers are under-confident in how their practice needs to be adapted. The barriers to effective implementation have been well described by the likes of Crawford (2007, 2014) and draw attention to the fact that there is not a single definition for inquiry; however, there are some commonly-held agreements about the principles applicable at primary and secondary stages of education:

- Learners are engaged by scientifically oriented questions;
- Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically-oriented questions;
- Learners formulate explanations from evidence to address scientifically-oriented questions;
- Learners evaluate their explanations giving due regard to alternative explanations, particularly those reflecting scientific understanding; and
- Learners communicate and justify their proposed explanations.

Through experimental and quasi-experimental design, some researchers have concluded that students in groups taught through an inquiry-based pedagogy did out-perform the students in the control group (cited in Furtak *et al*, 2012) and the impact of learning was maintained over an extended period of more than one year.

A survey into science education in schools by the English schools' inspection team, Ofsted, produced an influential report, *Maintaining Curiosity* (Ofsted, 2013) that clearly states that the best science teachers are those who set out to '*first maintain curiosity*' in their pupils, which not only fosters positive attitudes and enthusiasm for science but also helps pupils fulfil their full potential. It goes on to explain that pupils need to discover concepts through observing scientific phenomena and undertake investigations for themselves. Because of the way in which science is taught, their curiosity is maintained and they persevere with the task in hand. Through students' positive experience of science, it is more likely to translate into a feeling of wanting to continue to study science, use science understanding and knowledge both in formal and informal settings, and ultimately contribute to their capacity to become well-informed citizens.

The latest changes to the English National Curriculum for Primary Science (DfE, 2013) includes an explicit section called 'working scientifically'. It states that inquiry skills need to be taught within an embedded approach of investigations, inquiry and experiments so that pupils learn to use a variety of approaches to answer relevant scientific questions. This has to be done within the content aspects of science knowledge, so that through exploration and talking about their thinking they

have a deeper understanding of a wide range of scientific ideas. By the end of the primary phase, they should be raising their own questions and selecting the most appropriate ways to answer different types of scientific inquiry. They also need to understand how to analyse functions, relationships and interactions in a more systematic way than previously and build on their earlier experiences to develop the following specific inquiry skills:

- observing over time;
- pattern-seeking;
- identifying, classifying and grouping;
- comparative and fair testing (controlled investigations); and
- researching using secondary sources.

During the last two years of primary phase (Key Stage 2), the statutory guidance states that pupils should be taught to use the following practical scientific methods, processes and skills through the teaching of the programme of study content (DfE, 2015):

- planning different types of scientific inquiries to answer questions, including recognising and controlling variables where necessary;
- taking measurements, using a range of scientific equipment, with increasing accuracy and precision, taking repeat readings when appropriate;
- recording data and results of increasing complexity, using scientific diagrams and labels, classification keys, tables, scatter graphs, bar and line graphs;
- using test results to make predictions to set up further comparative and fair tests;
- reporting and presenting findings from inquiries, including conclusions, causal relationships and explanations of and a degree of trust in results, in oral and written forms such as displays and other presentations; and
- identifying scientific evidence that has been used to support or refute ideas or arguments.

Yet, only in the non-statutory guidance does it explicitly promote the opportunity for the learners to make most of the choices:

'They should make their own decisions about what observations to make, what measurements to use and how long to make them for, and whether to repeat them; choose the most appropriate equipment to make measurements and explain how to use it accurately. They should decide how to record data

from a choice of familiar approaches; look for different causal relationships in their data and identify evidence that refutes or supports their ideas. They should use their results to identify when further tests and observations might be needed; recognise which secondary sources will be most useful to research their ideas and begin to separate opinion from fact' (DfE, 2015, Upper Key Stage 2 programme of study).

Unlike the primary (Key Stage 2) programme of study, the secondary school science curriculum for pupils aged 11-14 (Key Stage 3) 'working scientifically' is set out under four distinct headings:

1. Scientific attitudes: *Pay attention to objectivity and concern for accuracy, precision, repeatability and reproducibility. Understand that scientific methods and theories develop as earlier explanations are modified to take account of new evidence and ideas, together with the importance of publishing results and peer review. Evaluate risks.*

2. Experimental skills and investigations: *Ask questions and develop a line of inquiry based on observations of the real world, alongside prior knowledge and experience. Make predictions using scientific knowledge and understanding. Select, plan and carry out the most appropriate types of scientific inquiries to test predictions, including identifying independent, dependent and control variables, where appropriate. Use appropriate techniques, apparatus, and materials during fieldwork and laboratory work, paying attention to health and safety. Make and record observations and measurements using a range of methods for different investigations; and evaluate the reliability of methods and suggest possible improvements. Apply sampling techniques.*

3. Analysis and evaluation: *Apply mathematical concepts and calculate results. Present observations and data using appropriate methods, including tables and graphs. Interpret observations and data, including identifying patterns and using observations, measurements and data to draw conclusions. Present reasoned explanations, including explaining data in relation to predictions and hypotheses. Evaluate data, showing awareness of potential sources of random and systematic error. Identify further questions arising from their results.*



4. Measurement: *Understand and use SI units and IUPAC (International Union of Pure and Applied Chemistry) chemical nomenclature. Use and derive simple equations and carry out appropriate calculations. Undertake basic data analysis including simple statistical techniques.*

While the identification of specific inquiry skills as described within 'working scientifically' has helped identify the need for process skills to be taught, it could also be argued that the way the statutory guidance has been presented might be counterproductive and promote a mechanistic approach to addressing just the skills explicitly identified. Teachers may struggle to recognise the need to go beyond these and ensure a wide range of inquiries are undertaken, not just 'fair testing'. Furthermore, it is not straightforward for teachers to easily understand how the skills being introduced in the primary phases of education relate to the skills identified within the early phases of secondary education. This poor clarity about continuity in inquiry skill development could account for a lack of clear progression in inquiry capabilities across the transition phase. The discontinuity could inadvertently promote (and explain) differences in the ways that primary and secondary investigations, inquiries and experimentations are carried out. As previously stated, an over-reliance on closed and highly structured inquiries might be contributing to a continuing lack of interest in science education, particularly from pupils who have not previously been perceived as high achievers within the primary setting.

Transition

The period between the end of primary phase and the start of secondary has received extensive interest in the past in relation to smoothing out issues related to transition (Wellcome, 2009; Ofsted, 2015; Russell, 2009). This is not a new area of study, yet remains relevant due to the well-reported dip in pupil attainment during this move from primary to secondary school. This could be explained by changes in teaching pedagogy, the curriculum, adapting to different school cultures, as well as emotional factors associated with human growth during the onset of puberty. However, there are noticeable differences in the duration of decline associated with science compared to

mathematics or English (Allen, 2016; Wellcome, 2009). These two subjects make a rapid recovery, which, interestingly, is not mirrored in the sciences, where pupil disengagement continues beyond what could be attributed to the previously outlined factors associated with the transition.

Topping (2011) comments that the quality of teaching is influential in shaping pupils' attitudes towards science, with pupils reporting more favourably on the teaching of primary science than secondary (p.274). He notes that the enjoyment gained from practical primary science activities can be lost on transfer to secondary school, as the taught curriculum can be both daunting and stimulating, with a dramatic change in teaching approaches. He also draws attention to a view that secondary teachers can underestimate pupils' innate academic ability (p.273) and this transition point is also when changes in pupil identity occur with the construction of 'self', which can be accompanied by a loss of self-esteem resulting in diminished pupil motivation and increased anxiety.

The recent Ofsted report, *Key Stage 3: The wasted years?* (2015), acknowledges the effective work achieved in addressing pastoral matters on transfer, such as getting familiar with the new school surroundings and undertaking 'bridging work', where a topic is started in the last term of primary school and completed during the first term of secondary. However, it also states that it is still not uncommon to find pupils bemoaning the fact that subject matter covered in primary school is repeated at the same degree of complexity at secondary school (Ofsted, 2015; Murphy *et al*, 2016). This tendency for secondary schools to make a 'fresh start' is missing the opportunity to build on the knowledge, understanding, skills and competences that pupils come with and fails to embed or develop them at Key Stage 3 (Ofsted, 2013; Symonds, 2015), which is likely to be a contributory factor in pupils' growing lack of interest in science education.

In addition to this, the findings from the ASPIRES project (DeWitt *et al*, 2011, p.21) claim that the period between 10 and 14 years of age provides a key opportunity to develop an individual's positive science identity, arguing that the way science is taught (along with parental factors) has a big influence in shaping an individual's science identity



and that, by age 14, this has become very resistant to change (DeWitt & Archer, 2015, pp.4-5).

Research indicates, therefore, that not only is it challenging for teachers to successfully apply inquiry pedagogies, but there are also different curricular expectations for primary and secondary teachers. There are also tensions in appreciating the nuanced pedagogies of teaching *about* inquiry, *through* inquiry or *doing* an inquiry. Alongside this, the lack of explicit practice promoting open or guided inquiries could suggest why children and students are likely to experience quite different inquiry opportunities pre- and post-transition to secondary school. This article suggests then that there is a need for clarity in the ways in which teachers should support learning progression in the development of inquiry skills and competences.

Conclusion

While transfer to secondary school is a time of excitement and anxiety for pupils, it is also an ideal opportunity for teachers to consider more carefully the development of inquiry skills from the learners' perspective. By focusing more on the continuity of effective teaching principles, such as those advocated through an inquiry-based pedagogy (as described in numerous European projects and research from around the world), the progression of inquiry skills, key competences and behaviours can be more effectively nurtured for long term impact. This might help towards addressing the drop in science attainment and better support secondary teachers in their drive to focus on the pupils' academic needs as effectively as they have done on their pastoral needs.

However, it is not uncommon to find that many teachers in primary and secondary phases of education espouse a belief that supports IBSE as an effective pedagogy, yet have a naïve conceptual understanding of what it is or how to go about embedding it into their practice. This is further compounded in England by the way that science inquiry skills are presented within 'working scientifically' as a set of disconnected skills within specific phases of education, without explicit guidance on how they should evolve and develop so that the next phase can build on what has been experienced and achieved before.

The means to achieve this will be aided by further research that examines the similarities and differences between the way primary teachers perceive and enact IBSE and that of secondary science teachers, particularly in the transition period.

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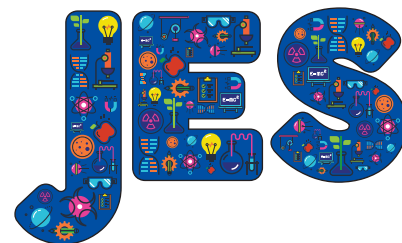
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No boundaries, No barriers: the PSTT International Primary Science Conference, Belfast, June 2016



What does a review of the literature suggest about the teaching of the nature and behaviour of matter during the transition years from primary to secondary



● Elizabeth Coppard

Abstract

This paper critically examines key ideas from the research literature on the teaching and learning about the nature and behaviour of matter in Key Stages 2 and 3 (ages 7-14). An argument is put forward that the current approach often fails to ensure meaningful learning of the particulate nature of matter and suggestions are offered for a different curriculum model.

Keywords: particle model; substance; primary-secondary transition

Introduction

Since the introduction of the National Curriculum (NC) in 1988, numerous studies (Braund, 2016) have revealed problems in the continuity and progression of children's learning of science as they transfer from primary to secondary schools. This paper focuses on the teaching and learning of a specific, vitally important, topic area of science taught in primary and secondary schools, that of the nature and behaviour of matter.

The existing literature on research about how students conceptualise matter is extensive (Hadenfeldt, Liu & Neumann, 2014). It is well documented that many learners fail to gain a meaningful understanding of chemical change at Key Stage 4 (ages 14-16) and beyond, and that this is largely due to a failure to understand the particulate nature of matter when it is taught earlier in the primary and secondary school science curricula.

The purpose of this paper is to bring together and critically examine key ideas from the (science education research) literature, which have an important bearing on the teaching and learning about the nature and behaviour of matter in primary and secondary schools, and offer some suggestions for a way forward.

I will argue that the way we currently teach about the nature and behaviour of matter in English primary and secondary schools is not fit for purpose and can, under certain circumstances, inadvertently encourage learners to develop alternative conceptions, which are not in keeping with scientific orthodoxy. I will suggest that, for effective teaching of the subject, a curriculum is needed that is conceptually coherent across the key stages, taught from the perspective of the 'big ideas' in science and based within a 'substance' rather than a 'solid, liquid and gas' framework. This paper is divided into three parts. The first part will discuss the fundamental importance of the topic and how it is presented in the National Curriculum. The second section presents a critical overview of the research literature in the area. It begins with a brief consideration of the reported studies on the problems encountered in science learning following transfer from the primary to secondary school. A concise examination of the extensive literature on children's understanding of the nature and behaviour of matter follows, and then leads into a discussion of the importance of the scientific notion of 'substance'. The significance of a 'big ideas' framework and conceptual coherence is then highlighted. Part 3 draws together the ideas from the literature and presents a suggestion for a different curriculum model for teaching this fundamental topic during the middle years of schooling.

Part One

The concept that matter is made up of infinitesimally small particles is one of the fundamental ideas underpinning human understanding of the world. It is essential for comprehending much of the science in the secondary school curriculum, and for any meaningful interaction with the science that is the foundation of most of our daily lives in the 21st century. Without an adequate scientific literacy



(taken to be understanding and applying scientific ideas), children are unlikely to be well positioned to contribute to the scientific workforce or enter into informed debate about the many socially important issues that beset us all.

It follows, then, that the nature and behaviour of matter needs to be a core part of the school science curriculum for children from age 5-16 years.

The fundamental importance of understanding about the nature and behaviour of matter is recognised at statutory level. The NC for Key Stage 1 (ages 5-7) (KS1) requires that children distinguish between objects and materials and explore simple physical properties of materials. In Key Stage 2 (ages 7-11) (KS2), this is taken further and children are required to investigate solids, liquids and gases, changes of state and separation of mixtures. The particulate nature of matter, atoms, elements and compounds and chemical change are introduced at Key Stage 3 (ages 11-14) (KS3).

There are, however, a number of serious criticisms that can be made about the way the NC documents are written and presented to teachers, which can inadvertently have serious detrimental effects on the teaching and learning of this material.

Firstly, the primary and secondary curricular policy documents lack coherence, both conceptual and in terms of their structure. In the KS1 and KS2 programme of study, there is a loose attempt to define some sort of conceptual progression in that what is to be taught is laid out as statements to be taught in particular years. At KS3, however, there is just a series of outcome statements, further complicated by categorising some as 'chemistry' and some as 'physics'. This categorisation into physics and chemistry statements not only breaks up the 'flow' of the story of the 'big idea' of the nature of matter but, when operationalised in school teaching schemes, might well mean that the material is taught by different teachers, which could give rise to conceptual confusion.

Secondly, the way the curriculum is written and presented at both key stages not only does not help children to acquire the non-intuitive scientific concept of 'substance', but also arguably actively promotes the acquisition of non-scientific alternative conceptions.

Part Two

Children begin to form their own intuitive ideas about matter, many of which differ in significant ways from accepted scientific orthodoxy, from a very early age (Driver, 2000). As they progress through primary school and into the early years of secondary school, these ideas are challenged through tuition. Many of these ideas are tenaciously held and persist, in some cases, through all phases of schooling and into adulthood. It has been suggested recently (Johnson, 2014) that some of these alternative conceptions are inadvertently encouraged by certain approaches to teaching.

It is now well established, from a variety of studies, (Braund, 2008) that many children experience a post-transfer 'dip' in their interest and attainment in science after they make the transition from primary to secondary school.

Much of the literature that has been published on primary to secondary transition in science suggests that teachers in secondary schools frequently fail to refer to learners' previous science learning experiences and many distrust the assessed levels of performance reported by the primary schools at the end of KS2. New secondary school students commonly encounter significant differences in learning environments, teaching approaches and teachers' language and are often required to repeat work done in the primary school, without a sufficient increase in challenge. These factors result in many Year 7 (age 12) students losing interest in science (Galton, 2009). This becomes particularly important when discussing the teaching and learning of the nature and behaviour of matter, for a variety of reasons.

Firstly, the particulate nature of matter is conceptually highly abstract and chemistry discipline-focused. It is more likely, than for example a biology topic such as functions of animal parts, that a specialist science teacher at secondary level (mistakenly or otherwise) will mistrust what the children have learned about the nature of matter. As secondary teachers are responsible for building complex understandings during KS3, there may well be a lack of confidence in reported assessment levels and the possibility of discounting learners' primary school experiences.

Secondly, the language that is used in this subject area, and which has a very definite meaning in science (e.g. terms such as *melt, dissolve, mixture, substance, particle, evaporate, boil*), is familiarly used in a much looser way in everyday discourse. Lastly, there are surprisingly few examples to choose from when exemplifying such things as changes of state under normal school classroom or laboratory conditions. As a result, it becomes important for secondary teachers to ensure that, although they may well have to repeat or refer to similar experiments and ideas that learners encountered first in primary school, the new activities are presented with increased challenge. An awareness of the importance of firstly understanding the level of the child's initial conceptualisation, and then the knowledge of knowing how to support an increasingly abstract understanding, is essential.

A considerable amount of literature has been published in the last 40 years on the teaching and learning about the concepts of matter in science education. The great majority of this research has been focused on elucidating learners' ideas about matter, mapping out their 'alternative conceptions' and designing 'learning progressions' to inform curricula planning and against which to validate assessment methods (Tsaparlis & Sevan, 2013).

Several key reviews of the research literature into children's development of concepts of matter over the last 20 years have highlighted how learners conceptualise matter and how their understanding develops and changes over time. Notable amongst these studies are Andersson (1990), Liu and Lesniak (2005) and Hadenfeldt *et al* (2014).

Analysis of the many studies carried out showed that, during their years of school instruction, learners' ideas could be grouped into a few major categories. Johnson (2013) has, to my mind, produced the most useful categorisation, which distills children's ideas about matter into four distinct particle models:

Model X: Continuous substance

Model A: Particles are in the continuous substance

Model B: Particles are the substance, but with macroscopic character.

Model C: Particles are the substance; properties of state are collective.

According to Johnson, learners' ideas seem to move at differing paces along an 'idea track'. They start off with the notion that matter is continuous. Gradually, this changes to an acceptance of a particulate model, although initially one in which the particles are imagined to be inside some sort of continuous material. Their ideas slowly develop into one where the particles are accepted as the matter itself, but at first the particles are ascribed macroscopic character. The final model is the accepted scientific one of matter as composed of particles and the properties of matter due to the collective behaviour of the particles.

There is a significant amount of evidence in the recent literature (Johnson, 2014) that points to students' understanding of the central concept of chemistry, the notion of 'substance', as a crucial feature in helping students comprehend the nature and behaviour of matter and chemical change. A 'substance' is defined as a unique kind of 'stuff', identified by certain invariant properties that do not depend on shape or amount of the sample of the 'stuff'. Johnson draws on extensive research to argue cogently that the focus in the KS2 National Curriculum on grouping 'stuff' into solids, liquids and gases before children have mastered the concept of substance encourages the development of alternative conceptions. He suggests that, because of the attention given to classifying samples of materials into these three groups, learners can perceive that solids, liquids and gases are three different kinds of 'stuff'. These alternative conceptions frequently persist into secondary schooling and beyond, severely hindering further learning about states of matter and chemical change.

In addition, he points out that, if learners are not able to fully comprehend the concept of 'mixtures', then problematic materials such as gels and pastes cannot be dealt with satisfactorily.

Johnson (2013) cites evidence to suggest that, although the main line of progress from Model X through A and B to the scientifically accepted Model C is unlikely to change, teaching through a 'substance'-based framework rather than a 'solid, liquid and gas' framework is likely to result in a much improved rate of progress.

The fragmented nature of the science curriculum, which is exemplified in part by the 'substance'

versus 'solids, liquids and gases' debate, was highlighted by the two reports on the 'Big Ideas of Science Education' (Harlen *et al*, 2010, 2015). Harlen and colleagues argue that part of the solution to some of the many problems inherent in school science education is to '*conceive the goals of science education not in terms of the knowledge of a body of facts and theories but a progression towards key ideas*'. They put forward a suggestion for organising the school science curriculum around 14 'big ideas': 10 'ideas of science' and 4 'ideas about science'.

The 'big ideas' focus is developed by Taber, who stresses the importance of integrating concepts in the curriculum to ensure curriculum coherence, and emphasises some of the issues that have particular relevance to chemistry concepts. The shifting of concepts over time and chemistry's use of multiple models and representations to understand target concepts are highlighted by Taber as uniquely problematic in chemistry teaching (Taber, 2015).

This brings up a key point, which seems to be barely touched upon in the literature, that of whether we should put more emphasis in some areas of primary science education on teaching children about the scientists' use of models. The particles that matter is made out of are non-observable phenomena. Scientists can only work with representations and models of these phenomena. In the NC policy documents and in some of the published schemes of work, particles are presented (to children) as true pictures of these non-observable entities.

A problem arises when learners perceive these models as a completely true picture of reality. When subsequently they come across something where the model fails slightly, they come unstuck. For example, when presented with a simplified picture of particle behaviour during change of state, if they are led to believe that this is 'what the particles do' then, as soon as they meet a situation where the model is not sophisticated enough for explanation, for example the increase in volume of ice when water freezes, they find it extremely difficult to understand.

Part Three

So I would argue, in order to make a real difference to the teaching and learning of the nature and behaviour of matter across all phases of schooling, we need a curriculum:

- that takes account of, and addresses, the problems (highlighted above) associated with the transition from primary to secondary;
- that is conceptually coherent and organised through a 'big ideas' framework;
- that utilises the extensive evidence accumulated to date about how children learn and come to understand complex conceptual ideas in science;
- that teaches overtly how scientists use models to represent and understand unobservable entities; and
- which foregrounds the concept of a 'substance' and does not use a 'solids, liquids and gases' framework within which to teach about the particulate nature of matter.

This is not going to be an easy undertaking. First and foremost, it will need continuity between primary and secondary curricula, not only in the way that the curriculum policy and guidance documents themselves are set out, but also in the ways that the curriculum is interpreted and enacted by teachers in both primary and secondary schools. It is essential that learners are able to follow conceptually coherent pathways as they transfer from primary to secondary school.

In order to accomplish this, there will inevitably need to be more liaison between primary schools and the secondary school that the primaries feed into. This is obviously a hugely problematic area, given the numbers of individual schools involved and the enormous time constraints on teachers in both key stages.

The literature on transition suggests that by far the majority of work aimed at improving continuity and progression in learning science as youngsters move from primary to secondary school has been in the form of 'bridging units'. These are units of work on a common theme that are started in primary school and completed during the first few weeks in Year 7.

To date, however, there is little evidence in the literature that other approaches to this problem have been explored.



An argument for a curriculum based on conceptual coherence implies that those teaching the curriculum must possess a similar conceptual framework and that the curriculum materials used by the teachers must be based on the same conceptual framework. So, I am suggesting that it is not enough to simply design an appropriate curriculum; we need to ensure that teachers in both key stages are approaching it through similar conceptual frameworks and using curricular materials that are similarly aligned. In order to do this, more research needs to be done on elucidating the similarities and differences between primary and secondary teachers' understanding of the nature and behaviour of matter, and the way that the curriculum is interpreted and enacted in both key stages. Primary and secondary curriculum materials (both statutory and non-statutory) must be examined to see if the way in which concepts are treated and applied is consistent.

Because of the conceptual challenges inherent in this highly abstract concept, learners need to be exceptionally well supported in a manner appropriate to their cognitive development at every key stage. This can only be properly achieved if there is good continuity and progression of the teaching of this topic across all phases of schooling.

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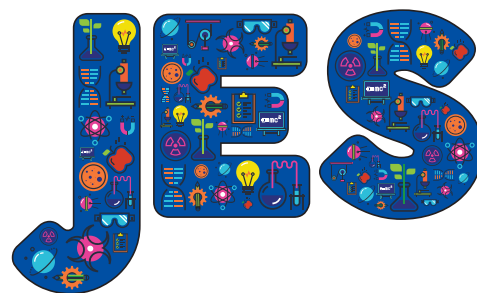
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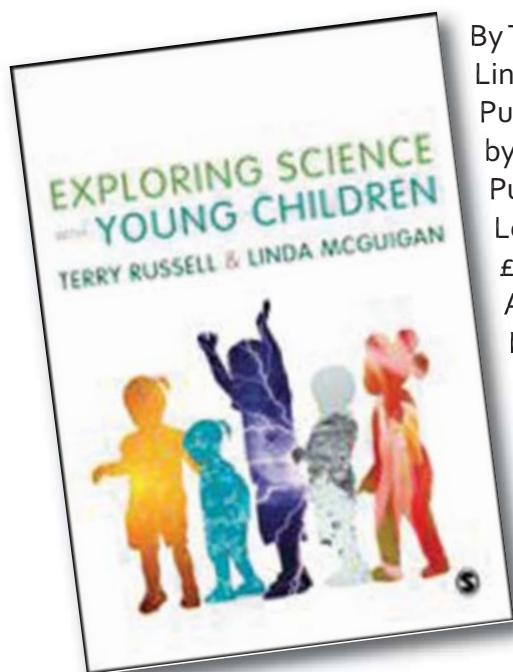
No boundaries, No barriers: the PSTT International Primary Science Conference, Belfast, June 2016



Resource Review



Exploring science with young children: A developmental perspective



By Terry Russell and Linda McGuigan.
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**Shortlisted for the
2016 ASE Book of the Year Award.**

This is a book for professional teachers. Targeted at teachers and educators concerned with teaching children from 3-7 years old, it takes a research-driven reflective approach that integrates the authors' strong philosophy about teaching and learning with concrete examples from their extensive experience as educators. It is unashamedly demanding on readers, who must grapple with specific elements of teaching this age range to reach the satisfying goal of rethinking their own ideas. In this, Russell and McGuigan reward those teachers and practitioners who wish to reflect deeply about their work with young learners with a fulfilling goal of seeing achievement from a wholly professional perspective. They are not content to structure their arguments based on any particular curriculum model, but rather to

reform thinking through pauses for thinking, reflection and some background science. Teacher educators will find this book a refreshingly different approach from other books that take the view of a teacher being someone with deficits that should be filled, of a teacher that should adopt prescribed routines to 'get through' a daily grind. They see teachers, and teacher educators, as active and creative participants in the education process, as opposed to passive recipients of hints and tricks purveyed by others.

The book begins with an extensive introduction, including substantial biographies of the authors to explain their thinking about 3-7 teaching and learning. Here the book is highly unusual, recognising that personal views shape and develop their approach to science teaching and learning, including for those with special needs. Even the title presages the content, with the use of 'with', rather than 'to' as is too often the norm. Russell and McGuigan see teachers and practitioners as learners too. As the publisher says of Hattie (2015), referring to his open-access book, '*Visible Learning means an enhanced role for teachers as they become evaluators of their own teaching. According to John Hattie, Visible Learning and Teaching occurs when teachers see learning through the eyes of students and help them become their own teachers.*'

The chapter headings point to their very different kind of writing:

- Introduction
- The nature of early years science
- Finding out children's ideas
- Developing conceptual understanding in science
- Working scientifically and developing science inquiry skills
- Encouraging the expression of ideas
- The uses of technology to support learning
- Planning, assessment and record keeping

In the introduction, the authors challenge the reader with the section on combating inequality, noting the wide gap that already exists in children's experiences and literacy before formal school begins. They do not accept that science simply 'offers children opportunities to encounter new vocabulary', (p.11), for so do other subjects. They see science calling for listening to arguments (to teacher/practitioner and to each other), thinking, reflecting, reasoning and expressing, within contexts that are tangible and therefore real in their lives. Sometimes specialist language has to be used, but other language is also particularly important. The section on representation of knowledge, multi-modality and metacognition acknowledges the many different ways in which we communicate, via models, or re-presentations as they put it, and using so many different modes, and ideas especially taken up with drawings and cameras later. They pose the rarely expressed thought that these young children can think about their own thinking, i.e. be metacognitive.

In the chapter, *The nature of early years science*, they deal with conceptual understanding, science processes, rules associated with the acceptance of scientific knowledge, and the nature of scientific discourse, in a very readable way. They deal with the issue of confidence and competence of teachers and practitioners in a very gentle and supportive way. They choose not to dwell strongly on subject knowledge matters, providing some examples where they thought it was necessary. I would have appreciated more of these, since I am all too aware that confidence increases as teachers understand more and more. I did appreciate their introduction of the value of children's fictional stories, both as a route to learning accurate science knowledge and also as a way of discussing differences between fictional and factual knowledge.

As I construct this review, I know that I cannot do all of the content justice, but the chapter on uses of technology builds on how such young children are

now familiar with cameras and tablets for recording observations, and how much these can be used as alternatives or as complementary to traditional forms of recording. Of course, widely available video, and Internet-based resources such as animations and audio evidence, allied to 3D models (soon to be supplemented by 3D printing), has done so much to extend horizons. I do remember a 5 year-old girl in a rural Australian school, 20 years ago, inviting me to join her as she held an Internet-based chat with a girl in another school a long distance away. She handled the equipment ('sit here so that the camera can see you') and supported me most fluently as she directed the event. How much more have they developed since then, if we give them the chance?

The chapter on assessment and record keeping places great emphasis on the role of the child in record keeping, while acknowledging the importance of milestones that need to be recognised. These link to targets and benchmarks that are part of our education cultures, but Russell and McGuigan emphasise sharing these with the children, giving them as much responsibility as possible for their own learning.

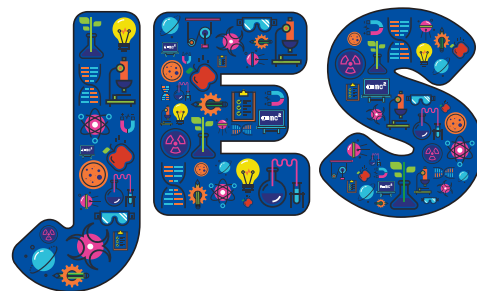
It has been very rewarding reading this book. It has provoked some new thinking on my part, and consolidated some existing ideas. I am sure many readers will also gain so much from reading it.

Reference

Hattie, J. (2015) *What doesn't work in education: The politics of distraction*. Open Ideas at Pearson, downloadable at http://visible-learning.org/wp-content/uploads/2015/06/John-Hattie-Visible-Learning-creative-commons-book-free-PDF-download-What-doesn-t-work-in-education_the-politics-of-distraction-pearson-2015.pdf

John Oversby

Contributing to JES



About the journal

The *Journal of Emergent Science (JES)* was launched in early 2011 as a biannual e-journal, a joint venture between ASE and the Emergent Science Network and hosted on the ASE website. The first nine editions were co-ordinated by the founding editors, Jane Johnston and Sue Dale Tunnicliffe, and were the copyright of the Emergent Science Network. The journal filled an existing gap in the national and international market and complemented the ASE journal, *Primary Science*, in that it focused on research and the implications of research on practice and provision, reported on current research and provided reviews of research. From Edition 9 in 2015, *JES* became an 'open-access' e-journal and a new and stronger Editorial Board was established. From Edition 10, the copyright of *JES* has been transferred to ASE and the journal is now supported by the Primary Science Teaching Trust (PSTT).

Throughout the changes to *JES*, the focus and remit remain the same. *JES* focuses on science (including health, technology and engineering) for young children from birth to 11 years of age. The key features of the journal are that it:

- is child-centred;
- focuses on scientific development of children from birth to 11 years of age, considering the transitions from one stage to the next;
- contains easily accessible yet rigorous support for the development of professional skills;
- focuses on effective early years science practice and leadership;
- considers the implications of research into emergent science practice and provision;
- contains exemplars of good learning and development firmly based in good practice;
- supports analysis and evaluation of professional practice.

The Editorial Board

The Editorial Board of the journal is composed of ASE members and PSTT Fellows, including teachers and academics with national and international experience. Contributors should bear in mind that the readership is both national UK and international and also that they should consider the implications of their research on practice and provision in the early years.

Contributing to the journal

Please send all submissions to:
janehanrott@ase.org.uk in electronic form.

Articles submitted to *JES* should not be under consideration by any other journal, or have been published elsewhere, although previously published research may be submitted having been rewritten to facilitate access by professionals in the early years and with clear implications of the research on policy, practice and provision.

Contributions can be of two main types; full length papers of up to 5,000 words in length and shorter reports of work in progress or completed research of up to 2,500 words. In addition, the journal will review book and resources on early years science.

Guidelines on written style

Contributions should be written in a clear, straightforward style, accessible to professionals and avoiding acronyms and technical jargon wherever possible and with no footnotes. The contributions should be presented as a word document (not a pdf) with double spacing and with 2cm margins.

- The first page should include the name(s) of author(s), postal and e-mail address(s) for contact.



- Page 2 should comprise of a 150-word abstract and up to five keywords.
- Names and affiliations should not be included on any page other than page 1 to facilitate anonymous refereeing.
- Tables, figures and artwork should be included in the text but should be clearly captioned/ labelled/ numbered.
- Illustrations should be clear, high definition jpeg in format.
- UK and not USA spelling is used i.e. colour not color; behaviour not behavior; programme not program; centre not center; analyse not analyze, etc.
- Single 'quotes' are used for quotations.
- Abbreviations and acronyms should be avoided. Where acronyms are used they should be spelled out the first time they are introduced in text or references. Thereafter the acronym can be used if appropriate.
- Children's ages should be used and not only grades or years of schooling to promote international understanding.
- References should be cited in the text first alphabetically, then by date, thus: (Vygotsky, 1962) and listed in alphabetical order in the reference section at the end of the paper. Authors should follow APA style (Author-date). If there are three, four or five authors, the first name and *et al* can be used. In the reference list all references should be set out in alphabetical order

Guidance on referencing

Book

Piaget, J. (1929) *The Child's Conception of the World*. New York: Harcourt

Vygotsky, L. (1962) *Thought and Language*. Cambridge. MA: MIT Press

Chapter in book

Piaget, J. (1976) 'Mastery Play'. In Bruner, J., Jolly, A. & Sylva, K. (Eds) *Play – Its role in Development and Evolution*. Middlesex: Penguin. pp 166-171

Journal article

Reiss, M. & Tunnicliffe, S.D. (2002) 'An International Study of Young People's Drawings of What is Inside Themselves', *Journal of Biological Education*, **36**, (2), 58–64

Reviewing process

Manuscripts are sent for blind peer-review to two members of the Editorial Board and/or guest reviewers. The review process generally requires three months. The receipt of submitted manuscripts will be acknowledged. Papers will then be passed onto one of the Editors, from whom a decision and reviewers' comments will be received when the peer-review has been completed.

Books for review

These should be addressed and sent to Jane Hanrott (JES), ASE, College Lane, Hatfield, Herts., AL10 9AA.