PRIMARY TEACHERS' UNDERSTANDING OF SCIENCE INQUIRY: INFLUENCES ON THEIR TEACHING AND FORMATIVE ASSESSMENT PRACTICE

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Abstract: In England, recent changes to the National Curriculum for primary science (Great Britain, DfE, 2013) have tried to respond to the legacy of national tests set at the end of primary schooling (10-11 years old) and establish a better balance between formative and summative assessment practice. Within this context, we have developed a professional development programme that aimed to support primary teachers in their teaching and assessment of science inquiry. Our research aims to investigate what kinds of professional development approaches support the formative assessment of primary science inquiry and how these are reinterpreted into teacher practice. This paper reports on the preliminary findings emerging from our study. Our data sources include written teacher reflections, audiorecordings of the professional development meetings and observed lessons and semistructured post lesson interviews. We draw from a multi-step, open-coding analysis of selected lesson observations and substantiate this with teacher discussions arising from the professional development sessions to extend our understanding of effective ways to guide teachers in transforming their teaching and assessment practice of scientific inquiry. Our preliminary analysis suggests that providing primary teachers with strategies to engage their learners with specific inquiry skills over a number of different contexts for inquiry enables the teachers to introduce more open approaches to dialogue in their inquiry lessons. These structures equip them with sufficient understanding of what to target and look for in children's answers that enable them to go beyond accepting or rejecting answers and, instead, facilitate discussion which allows children to share their ideas with others. We are still in the process of data collection and analysis. Further findings will have implications for professional developers and pre-service teaching. The findings also generate debate about professional learning and understanding of pedagogy and assessment in inquiry classrooms.

Keywords\: Primary Science, Professional Development, Assessment

BACKGROUND

Inquiry-based science education is shown to be associated with enhanced children's interest (Rocard, 2007) and attainment levels (Wilson, 2010) as well as teacher motivation. The characteristics of science inquiry in the classroom include students' involvement in questioning, reasoning, observing, conjecturing, data gathering and interpreting, investigative practical work and collaborative discussions and working with problems applicable to real life contexts (Bernholt, Rönnebeck, Ropohl, Köller & Parchmann, 2013). To achieve this scenario in the classroom requires teachers to adapt their teaching to allow students to make a larger input into the direction of the lesson and often teachers need to reconceptualise how they organise their classroom and resources for this to happen. The enactment of inquiry pedagogy also seems to be affected by teachers' understanding and perception of science inquiry, which can be traced to how it is characterized and defined in the curriculum, but also by how it is assessed and taught by individual teachers.

The formative use of assessment evidence is a key pedagogical driver to support and advance students' learning (Black & Wiliam, 2009) and is as applicable to inquiry as to other science activities. Ruiz-Primo & Furtak (2007) make a distinction between formal and informal formative assessment opportunities: Formal formative assessment are pre-planned opportunities within a lesson and involve pre-designed formative assessment activities (e.g. self- and peer- assessment tools such as traffic lights, using mini-whiteboards). The teacher is ready to step back, gather evidence, interpret this, plan and take next steps. Informal assessment opportunities are transient, immediate and often non-recordable forms of evidence. The assessment opportunities are not planned, they are triggered by what a teacher notices. The interpretations are much more immediate, spontaneous, intuitive and subconscious. Within a science inquiry lesson, Shalveson et al. (2008) identify these "teachable moments" as 'interactions on the fly'.

In the UK , the reported consequences of the emphasis that was placed on national testing of children in primary science (ceased in 2013) highlight its widespread impact on children's and teacher's engagement with classroom science. The pressure of testing has undermined children's self-esteem (Alexander, 2010) and diminished their motivation to learn science (Harlen, 2012). The high-stakes nature of these national tests has led teachers to focus their teaching practice on the preparation for tests (Harlen, 2013) at the expense of hands-on practicals. The testing requirements around assigning and reported levels has also led to a reduced focus on teachers' formative practice in primary science (Pollard et al, 2000).

Recent changes in the National Curriculum for primary science (Great Britain, DfE, 2013) have provided an opportunity to possibly address some of these consequences of high stakes testing. Primary teachers are now expected to report on children's science achievement at age 11 but there are no longer national tests that straitjacket the approach that teachers take to assessment. As a consequence, primary teachers seem to be largely left on their own in how to address teaching and assessing science inquiry. Many schools are seeking ways of completing this assessment effectively and this can cause concern for teachers. However, we view this from a different perspective. Because teachers are no longer directed what to do, our project offered teachers support in working out new ways of assessing which primarily serve the purpose of providing feedback for learning, while, at the same time, supplying information for making final summative judgements.

Findings from the Strategies for Assessment of Inquiry Skills in Science project show that teachers can be effectively supported in engaging with inquiry pedagogy through changes in their teaching and formative assessment practice (Harrison, 2014). Moving away from assessment of inquiry products towards assessing during inquiries (taking a formative stance) allowed teachers to make more accurate judgements on where their learners were in their learning. This is crucial for planning subsequent interventions to advance students learning.

To enable this to happen, we called on the support of a local authority advisor to work with us on setting up a teacher professional development programme with nine teachers from that particular area of London. We were aware that the provision of continuing professional development (CPD) opportunities to enable teachers to adapt and expand their pedagogical repertoire is valued by both the research and wider educational communities in the UK (EPPI, 2003, 2005). Fullan (2001) summarises that change might bring about revised curriculum materials and/or teaching practices and/or beliefs about curriculum and learning. Shulman (1986) highlights the role of CPD in transforming teachers' subject- specific knowledge into pedagogical content knowledge (PCK). Some of the effective characteristics of CPD programmes emerging from relevant studies include practical and real illustrations of how theory translates into classroom practice and which teachers actively experience (Jeanpierre,

Oberhauser & Freeman, 2005), using evidence that 'show teachers' work and students' learning' (Harrison et al, 2008), a learning professional community where teachers can talk together and grapple with the presented ideas and the implications that these may have on practice (Shulman & Shulman, 2004), ongoing support in school through coaching (Joyce & Showers, 1995) and significant opportunities for teachers to reflect on the impact that the experiences have had on their teaching and attitudes to learning (Adey, 2004).

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In this paper, we present preliminary findings of a study conducted in England within the Assess Inquiry in Science, Technology and Mathematics Education project (EU FP7).We draw from preliminary data to explore the processes of primary teachers' change when supported by a professional development course as they engage with the teaching and formative assessment of science inquiry.

PROFESSIONAL DEVELOPMENT PROGRAMME

Nine participant primary teachers embarked on a one year professional development programme. Over the duration of the programme, these teachers engaged in six half-day sessions that focused on the pedagogy and assessment of science inquiry. The programme aimed principally to raise teachers' confidence to do science inquiries and especially to embrace the learning opportunities that can arise when inquiries do not follow an intended path. This was achieved through the introduction of 9 inquiry lessons (see Table 1). These inquiry lessons were presented during the professional development sessions so that the participant teachers had an opportunity to do the inquiries for themselves, begin to consider how their class might approach these inquiries and have professional discussions with the other participant teachers about the kinds of resources, pedagogy and underlying subject knowledge that might be required for each inquiry.

Table 1: A summary of the UK primary inquiry lessons for ASSIST-ME 2014-2015

Inquiry	Summary
Mouldy bread	Children are presented with some samples of bread that have mould. 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.
Yeast	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.
Multi-coloured milk	Children are given some milk in a saucer. They are asked to observe what happens when several different food colouring 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?

Criminal Intentions	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.
Brilliant bubbles	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 encourage 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 of the three bottles and then take the bottles outside on a windy day or leave them in front of a fan for 30 mins. 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, 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.

Crucially, the participant teachers were assigned an inquiry skill focus for a whole school term (approximately 14 weeks). In England, the 2014 primary science curriculum presents inquiry as a collection of discrete skills (e.g. writing predictions) and within this curriculum, these skills are collectively known as 'Working Scientifically'. Through the professional development programme, specific success criteria for some of these discrete skills were introduced. During a period of 14 weeks, the teachers were expected to teach some of the introduced inquiry lessons, alongside their regular primary science teaching and to focus their children's attention on one discrete inquiry skill throughout. This emphasis on skills became the focus of teaching and assessment within science inquiry. So, while the general aim was to strengthen inquiry in these classrooms, the focus and specifically assessment was on discrete inquiry skills.

The participant teachers were also expected to engage with some professional literature and consider the implications of this for their practice. This expectation was emphasised through the use of a recently published teaching resource, 'It's not Fair!' (Turner, Keogh, Naylor & Lawrence, 2011). The participant teachers were each given a copy of this publication and regular written reflective tasks were set, in between professional development sessions, based on the reading of specific chapters within this book.

A significant feature of each professional development session was the substantial and planned professional dialogue where each participant teacher was given an opportunity to share their perception of the impact that this programme was having on their practice and their children's ability to do science inquiry. These discussions were skilfully facilitated by the local authority advisor so that they became more than simply sharing impact. These

participant teachers were challenged to reflect critically on aspects of their developing pedagogy and identify evidence from their practice (e.g. what questions they asked) and their children's learning (e.g. what the children said) to illustrate their reflections. To some extent, this dialogue forced an opportunity for teachers to make their implicit, subconscious formative practice explicit.

Research Questions

Our hypothesis is that primary teachers' confidence with and understanding of inquiry shape their approaches to teaching through inquiry and also how they engage with formative assessment in inquiry lessons. We will pursue how this understanding is beginning to be translated into formative practice as captured in their verbal interactions while teaching science inquiry. We explore this through the following research question:

What kinds of professional development approaches support the formative assessment of primary science inquiry and how are these reinterpreted into practice in the primary science inquiry classroom?

METHOD

This study follows a qualitative research approach (Cohen, Manion & Morrison, 2011). Our primary data sources draws 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 this primary aspect of the project, data was collected from 6 professional development days and 10 classroom lesson observations. Data triangulation is being undertaken using selected data collected from classroom observations, teacher interviews, and teacher meetings and written teacher reflections.

A multi-step analysis was applied to all transcribed lesson data. Firstly, in order to establish a unit of analysis, research field notes and the audio-recording was used to develop an overview of lesson. This helped to identify a macro unit of analysis, an episode within a lesson 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 appeared to make 'on-the-fly' comments were closely examined to explore and describe the formative practices used by the participant teachers during these episodes. At this point, the micro unit of analysis was typically each participant's speaking turn. An open-coding approach was used to analyse this unit of analysis (Cohen, Manion & Morrison, 2011). We initially adopted and then adapted a coding system developed by Ruiz-Primo and Furtak (2007) to analyse the episodes, referred to as ESRU 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). However, in the inquiry classroom, because the students take a more active role in the direction of the activities, there were some concerns as to whether the ESRU cycle provided an adequate system to capture the nuanced ways in which formative assessment works in such environments. While Ruiz-Primo and Furtak focused their interpretations of classroom dialogue on the number of completed ESRU cycles they found, our interest was more on the quality and purpose of the talk and its potential to provide feedback from learner to teacher and also teacher to learner. Indeed, we found that often teachers would often follow a student

response with another question, rather than provide a solution for the student, which tended to open up the dialogue more. To try and delve more deeply into the data we decided to construct a second layer of coding (see Table 2) that took into account whether the teacher response led to a more divergent form of dialogue that explored ideas further or whether it seemed to drive the dialogue into a more convergent dialogue towards a specific objective. We then used this two-layer coding system and categorization to complete our analysis and ensure common application and interpretation (see Tables 2 and 3). Multiple fragments of data were coded independently by two of the researchers to address inter-rater reliability.

Table 2. Teacher intention codes (second layer) adapted from (Torrance & Pryor, 2001)

Code	**Meaning**
TC (Convergent)	Instances where teacher asks questions to check if students are on intended path. These are questions that close down the discussion.
TD (Divergent)	Instances where the teacher asks probing questions or makes comments that probe and encourage thinking & discussion
TL (Lectures)	Instances where the teacher provides information through exposition or direct instruction e.g. to help students make sense of something, fill in a gap of knowledge, or give instructions on procedures.
TA (Affirms)	Instances where the teacher repeats or re-formulates student(s) contribution to give it value and/or to summarise

In this preliminary phase of data analysis, this paper will draw from an initial analysis of teacher reflections from the 6 observed professional development days and the multi-step analysis of 4 of the 10 observed lessons by 3 of the 9 participating primary teachers. The ages of the children engaging in the observed lessons were mainly 9-10 years old (Y5) and class sizes were typically 30. During an inquiry, observed classes worked in groups ranging between 3-5 children per group. In this paper, we use and explore our teachers' reflections from the professional development days to substantiate or challenge the interpretation of the lesson observation data. In this way, we begin to see both how they interpret what inquiry looks like in the classroom and their confidence in using strategies introduced within the professional development programme.

RESULTS

Analysis is still being completed and this paper reports on some of the emergent findings. This paper is based on 11 episodes from 4essons taught by 3 of the 9 participating primary teachers.

An analysis of episodes within selected lessons is beginning to illustrate how some of these participant teachers are using their formative practice to assess and develop science inquiry. On-the-fly comments made within episodes of whole class dialogue offer a rich opportunity for informal formative assessment. The open-coding of individual sentences and statements from the classroom dialogue within these identified episodes during the inquiry lesson provide a means of characterising the formative practice occurring during these and also

begins to indicate and explain factors that may constrain teacher formative practice in primary science inquiry.

In the example below (see Table 3), towards the end of an inquiry lesson on yeast, there is an episode where the teacher invites different students to share their written predictions with the whole class. The teacher elicits a prediction, the student shares, the teacher then gives some praise and, additionally provides feedback in a way that uses the student's prediction as a way of developing the whole class's understanding of what characterizes a successful prediction. In terms of formative practice, this primary teacher is explicitly sharing and using with their students the success criteria (introduced during the professional development days) associated with the learning goals of the inquiry lesson.

Table 3. Example of coding an episode from a lesson on yeast

Speaker	Line	Code layer1	Code layer2
T	**Ok, if you are just finishing off your predictions, then feel free to keep writing, then finish your sentence. Everybody else though, look this way. Now, I'd like a few people who have done some really good predictions to share. Now, what I mean by a good prediction is (teacher refers to success criteria on Interactive White Board) to make a guess, someone who has linked it with their reasons, someone who has used what they already know and has used their scientific knowledge to make their prediction. Who has done that? Hopefully everyone's hands should go up because they know what they should be doing. Ummm, Jamal, you have really impressed me today. Can you read your**	E	TA, TL,TC
	out please? Let's see if you have done all the bits.		
S	I predict that the yeast will rise up in the warm water because the warm water will heat the yeast and the yeast will release carbon dioxide.	S	
T	**That's great, well done Jamal**.	R	TA
T	**So Jamal said his prediction, he made his guess, didn't he. He said 'because' and said why, he said 'because heat will release the carbon dioxide'. But he didn't say why the heat will help. So the last thing you need to do is to say why you think the heat will help the yeast to release the carbon dioxide. Does anyone know or think why that heat will help? Anyone written the why the heat would help? Lauren what have you written?**	U,E	TL, TD
S	I predict that the warm water will be the right temperature because when you put bread in the oven, the oven needs to be warm.	S	

T	**Well done, so Lauren, made her guess, she said why and her reasons are to do with her prior knowledge. When you put yeast in the bread dough in the oven, you never put it on warm or cold, you put it on hot so she is using that to say why, what would be the best temperature. So, well done. These ideas are all good. Think about living organisms as well. What temperature do they work best in? Shia, tell me yours**.	R, U	TA, TL, TD

In this episode, the teacher helps the class share ideas and explore their understanding through using the success criteria. This focuses the learners on considering the reasons that students are providing as part of their hypothesis and, as such, allows the teacher to go beyond accepting answers as correct to exploring how well the ideas are expressed. At the same time, doing this in a whole class feedback session, enables the learners to reflect on and reconsider their hypotheses in comparison to the two presented and so begin to interpret what is meant by a good prediction.

The participant teacher perspective on their formative practice and what enables and constrains this during science inquiry is evident in the professional dialogues that occurred on the professional development days. Over the duration of the primary professional development, what has emerged is that supporting primary teachers in their epistemic understanding of inquiry (understanding what a good prediction/conclusion looks like) is informing how they use dialogue formatively during science inquiry. A key vehicle driving this has been the introduction of success criteria for different elements of science inquiry. In all the primary lessons observed, this was communicated to the class at the onset of an inquiry, using the interactive white board. The primary teachers make reference to these when they reflect during the professional development days as when they discuss what they notice about children's responses. They assess 'what they notice' based on these success criteria.

A key development emerging from participating teacher reflections during the professional days, illustrated in the reflection below, appears to be a recognition and acceptance (for some participant teachers) that their subject knowledge, specific to the activity is limited BUT that this will not necessarily impede dialogue during a science inquiry:

" … loved the bubble activity even though I was more scared of that because I didn't know the science behind it…it worried me in terms of the questions they might ask me. 'What makes the bubbles big and the molecules?'"

Local authority advisor asks him, "How did you handle that?"

"…I just put it to one side. I did as much research as I could and I went and did it with kids in my garden and then I thought, 'do you know what, I haven't got a clue…when I went to the class the next day, I thought, 'it doesn't make a difference', it's a case of what I can communicate to them."

Teacher T 13.5.15

Teacher reflections from the professional development days also reveal the significance of setting their science inquiry within a context that was authentic, relevant and motivational, for example:

"We started with Criminal Intentions because it was easier and we were more prepared for it. What I did was I set up a real crime scene and I got the barrier tape out and the site manager there giving his eye witness account of when he spoke to the police. He got his phone to ring and pretend it was the police…you know they were really in it, they really believed it until the end of the lesson when they saw the barrier tape by my side..."

Teacher S 13.5.15

The descriptions that these participating teachers share, during the professional development days, of how they set up the contexts for their primary science inquiries perhaps suggests that what facilitates their teacher attempt to guide students towards the intended inquiry goals using interactions on the fly is a careful consideration of the context. This consideration of context might enable these primary teachers to help their students make connections to prior, everyday experiences, promote a greater exploration of students' own ideas and this might strengthen their students' ability to predict and explain their observations. There is some evidence to suggest that these teachers are personalising the contextual nature of these activities.

DISCUSSION AND CONCLUSIONS

There is emerging evidence to suggest that the rationale, content and approach of the professional development experience that these participant primary teachers engaged with has impacted on their practice in the following ways:

- Developed formative practice in relation to science inquiry. These primary teachers used the success criteria for a specific science inquiry skill (introduced through the professional development) to develop their children's understanding of what effective science inquiry is. The success criteria allowed these teachers to provide crisper, more forensic and sophisticated on-the-fly formative feedback to children during the inquiry lessons. The success criteria also drew these teachers' attention to inquiry learning within science lessons and consequently raised their awareness of the potential formative evidence of learning (of inquiry) that is available during these science lessons. This developed formative practice informed the summative judgements that these teachers could make about the progress their class made in relation to science inquiry.
- Heightened confidence and creative freedom to plan and resource inquiries (within the bounded structure of the suggested inquiries). This enabled these primary teachers to consider how to contextualise these inquiries so that they were authentic and relevant to the children they were working with.
- An awareness (for some of the participant teachers) that their limited science subject knowledge need not constrain learner engagement with inquiry. Many of the participant primary science teachers freely admitted their lack of confidence with the subject matter. Over the duration of the professional development, some of these teachers felt more confident and comfortable with facilitating whole class discussions where they might not 'know the science answer'. For other participating teachers, their uncertainty with the underlying science subject matter still drove a need to acquire some background knowledge for themselves and their class in order to enable their class to improve their ability to do science inquiry.

There are several key features of the professional development approach that might have contributed to this impact on practice:

At the onset of the professional development experience, the participant teachers were introduced and given a sequence of inquiries. These inquiries were bounded in nature in that the expectation was for the class engage with the suggested inquiry as opposed to developing an inquiry in order to answer an inquiry question. The rationale behind this decision was to address the observed lack of time and confidence that these teachers had in teaching primary science. This rationale is echoed in the literature that highlights the current state of primary science practice in schools in the UK (e.g. Harlen, 2013).

Within these suggested inquiries, the participant teachers were asked to focus their teaching and assessment on a discrete inquiry skill. This skill (making a prediction or a conclusion) was further broken down into success criteria. In paying attention to just one skill over a sustained period of time (two school half terms-14 weeks) through a range of inquiries provided the training ground and focus that learners required to do this more systematically when these teachers were subsequently engaged their learners with complete inquiries.

After each professional development session, the teachers were given some specific reading and a written reflective task. This raised the importance and value of their ongoing pedagogical understanding. The choice of reading material and written tasks resulted in a teacher engagement with professional literature that was relevant and applicable to their practice.

A significant proportion of each professional development session was devoted to critical self-reflection on practice and impact on learning. During these discussions, the participant teachers shared the challenges that they were now experiencing as a result of this interaction between their professional development and their teaching and assessment of primary science inquiry. This creation of protected time for these teachers to reflect upon and share their evaluations of teaching and learning helped to develop their collective identity as a community of practitioners. The ensuing discussions were honest and expertly facilitated by the local authority advisors who ran the sessions and became a professional learning opportunity in itself.

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