HAVE WE GOT THE FORMULA RIGHT? COCONSTRUCTING MODELS FOR WORKING SCIENTIFICALLY IN THE PRIMARY CLASSROOM

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Abstract:
This paper explores the experiences of primary teachers collaborating together and with research scientists to explore and develop approaches to working scientifically and the teaching and learning of science enquiry in the National Curriculum Primary Science curriculum (England). The paper describes findings from case studies from five primary schools, which drew on the approaches of coteaching developed by Murphy & Beggs (2009). As co-creators of learning experiences, teachers and research scientists deconstructed their respective models of scientific enquiry and then collaboratively reconstructed events and lessons that aimed to engage children authentically in scientific endeavour. It illustrates how the dialogue and creation of learning experiences broadened the scope of children's experience of primary science enquiry, and focused attention onto the aspects of scientific research processes which challenge children and their teachers, such as effective question posing, the cyclical nature of investigation and peer review. This study is particularly pertinent as the revised Science National Curriculum policy in England is implemented, with its key emphasise on teaching children to work scientifically.

Content keywords: science enquiry, primary/elementary
Methodological keyword: coteaching

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1. INTRODUCTION

September 2014 marks the commencement of the role out of the revised National Curriculum for Science in England (DFE, 2013), against the backdrop of an ongoing theory-policy-practice divide. Such curriculum reform places increased demands on new and in-service teachers who must respond swiftly and practically to changing government policy whilst academic research hastens its' efforts to influence it. In the main, classroom practice remains reactive to policy over and above theory, especially as school assessment and accountability measures require swift response and attention from senior leaders.

The revised National Curriculum for all subjects in England contains the essential knowledge and skills that all children should learn, yet government mandates have been clear in their aims to not dictate *how* teachers should teach. Information provided to schools the Department for Education offers guidance to support teachers implementing the new curriculum, which for the primary and secondary teaching of science has been directed towards resources promoting more practical work. For most primary teachers, the use of schemes of work, professional development courses, published resources and books, on-line publications, social media and collaborative working parties provide a rich source of ideas and guidance. These aim to target teachers' competence and confidence in a wide variety of areas, such as science subject knowledge, investigative work, assessment practices, subject coordination and subject leadership. Influencing teacher confidence in these areas of science continues however to be a challenge (Harlen, 1995; Appelton 1997, Harlen & Holroyd 1997 ; Murphy & Beggs 2005, Murphy, Neil & Beggs 2007). OFSTED's evaluation restates these issues.

> Despite some positive initiatives, such as the Primary Science Quality Mark and the Association for Science Education's publication for primary schools 'Be safe', there has been insufficient professional development in science to tackle the lack of confidence among primary teachers, particularly in their understanding of scientific enquiry skills and the physical sciences. (OFSTED 2011)

Teachers report that their overall lack of science background knowledge, confidence and training to teach science effectively was the most significant issue facing primary science education. These factors alongside lack of resources, lack of time, overloaded science curriculum, large class sizes and lack of classroom assistance create challenging circumstances for teachers in school, especially for those wishing to teach scientific enquiry and undertake practical investigative work inside or outside of their classroom (Murphy & Beggs, 2005; Wellcome 2011).

'Working scientifically' appears in the new curriculum to specify 'the nature, processes and methods of science'. Guidance stresses that it should not be taught as a separate strand of learning but embedded within the content of biology, chemistry and physics. Key importance is placed on scientific enquiry including: observing over time; pattern seeking; identifying, classifying and grouping; compartive and fair testing; and researching using secondary sources (DFE 2013, p 4).

This paper reports on a 12-month study in which primary teachers and university research scientists deconstructed the way they approached the undertaking and teaching of scientific investigations – whether that be in their professional life (as research scientists) or the pedagogy they used (as teachers). It explores the influence of co-constructing learning opportunities between teachers and scientists on the teaching and learning of working scientifically in primary science. The outcomes of the discourses from 5 school cases are drawn upon which targeted the learning of infant and junior aged children (5-10 years). A coteaching model of practice guided the collaborations, based on Murphy et al. (2009), involving a collaborative process of planning, teaching and reflection. The paper reports on the models for scientific enquiry as exposed through the collaborations and considers the implications of these models as teachers and curriculum developers strive towards interpreting in practice the core NC aim of:

> Ensuring that all pupils:
> develop understanding of the nature, processes and methods of science through different types of science enquiries that help them to answer scientific questions about the world around them. (DFE 2013, p 3)

2. METHODOLOGY

This study was managed by a project leader who designed professional development opportunities for teachers and scientists, focused on enhancing awareness and confidence in the National Curriculum objectives related to practical science investigations, as referred to in the programmes of study as 'working scientifically'. The study comprised of three cycles of professional development and reflection events, interspersed by periods of school based activity. The main period of in-classroom activity fell in the Spring and Summer terms of the academic year. Dedicated time was given to explore through conversation and copractice with research scientists how similar/different authentic scientific investigation/endeavour was to what schools are asked to teach. Teachers and scientists were given funded time out of their work commitments.

The participant cohort included teachers from 5 primary schools (n=12) who all taught in urban/suburban localities and 7 researcher scientists. The teachers reported teaching science for 1-2 hours per week. Researchers were doctoral and postdoctoral scientists and engineers recruited voluntarily from the University of Manchester, and included cancer researchers, paleontologists, audiologist, mechanical engineers and material science specialist.

The project manager guided the cohort in the analysis of their respective ways of working, encouraging participants to deconstruct their approaches to practical work and to compare where similarities and differences lay with the purpose of jointly reconstructing a method of science enquiry that they could use with children. The group agreed on 'ideal' outcomes for working scientifically laying the foundations for the development of activities and classroom based activity, which spanned between 6 to 8 weeks of work.

Data was qualitative and included project leader reflective notes from formal and informal meetings/school visits, teacher and research scientist presentations, electronic communication/discourse and reflective statements. Two independent consultants, with knowledge and interest in primary science supported the collection and write up of case studies, allowing the project manager's perspective to be critiqued and triangulated. All the data was collated into separate case study reports and key themes drawn across them. Focus was paid to exploring the models of working scientifically constructed by the teacher-scientist partnership.

3. FINDINGS AND DISCUSSION

3.1 Models of Working Scientifically

The case studies showed three models for working scientifically emerging from the study which ranged from being strongly guided to the specific requirements of the new National Curriculum at the expense of the adoption of the scientists work practice, to that which was developed specifically in response to how the scientists explained their work practices at the expense of the NC objectives. The level of risk taking illustrated by the willingness to move away from the prescribed requirements could be aligned with the level of confidence in experience of the teachers and scientists involved, some of whom who held senior leadership positions in their school.

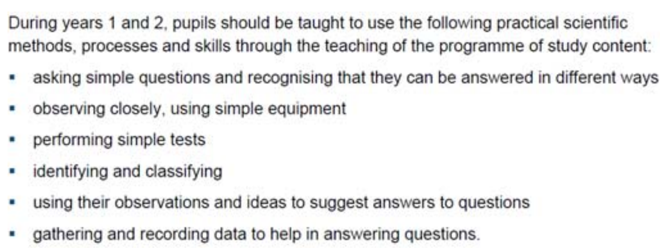
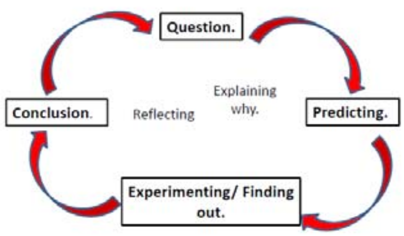
Following lengthy dialogue and exploration of how the scientists undertook their research, the group listed the 'ideal' aims for children's investigative work to include:

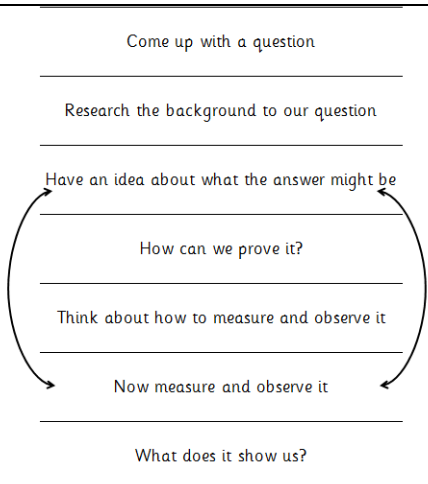
not having closed outcomes	collaborating, e.g. between different year groups
giving opportunity to make deductions	giving opportunity to take responsibility and lead learning, e.g. devising investigations (what will be tested and measured; how will it be tested and measured)
relating investigations to everyday life	questioning things
being creative	making an impact beyond themselves, e.g. on the whole school
starting from their own ideas	promoting observation
being involved in peer review/peer assessment to make sure work is to the right standard and find the absolute truth	helping explore the questions ‘What’s the next step?’ and ‘How could you explain it further?’
allowing for mistake making and risk taking	developing scientific conditions, e.g. control groups

Table 1: Ideal aims for children’s practice when working scientifically

The cohort did not seem to find difficulty identifying these aims however it was evident that both groups were interested in each other’s interpretations of them. In particular teachers found the notion of peer review unfamiliar as scientists spoke frankly about the somewhat competitive nature of publishing and the drive towards maintaining one’s status as an ‘academic’ through this process. All agreed that creativity and mistake making were core parts of science, however teachers expressed that the emphasis on subject knowledge acquisition and the drive towards increasing literacy and numeracy standards often left little time for such type of endeavours. Teachers also highlighted their own challenges with subject knowledge when helping children explore their questions further and sometimes found that they lacked the understandings of particular science topics to be able to explain observations and phenomena further.

The three models that emerged from the school activity can be represented as follows.

Model 1: National Curriculum (2013) *(ref. Appendix 1 for all NC age phase requirements)*	 During years 1 and 2, pupils should be taught to use the following practical scientific methods, processes and skills through the teaching of the programme of study content: ▪ asking simple questions and recognising that they can be answered in different ways ▪ observing closely, using simple equipment ▪ performing simple tests ▪ identifying and classifying ▪ using their observations and ideas to suggest answers to questions ▪ gathering and recording data to help in answering questions.
Model 2: 4 Phases	

Model 3: 7 Phase model	

Model 1 was used by three of the schools and represents the statutory requirements of the National Curriculum for children between the ages of 5-7 years, and specifications for older age groups were similarly used by teachers working in those age phases. Despite expressing desire and intent to diversify their approaches, these teachers seemed to find difficulty moving away from these requirements. This is particularly interesting as their activity in the project was acknowledged by their senior leaders, although they were not directly involved in the project, and despite their healthy discourse and interaction with their scientist collaborators they defaulted to what they were most familiar with once in the classroom. This is not to say that many of the ‘ideal’ aims were not achieved, indeed they encouraged children to be collaborative and creative, explore their own perceptions and investigations which related to everyday life, make deductions etc., and as such were fulfilling the requirements of the curriculum.

Model 2 emerged from a teacher of Early Years, children aged 5-6 years, working with a research scientist specialising in audiology. This was the smallest collaborative group in the study however one from which a cyclical model emerged, which in effect bridges the NC requirements and the ways of working promoted by the scientist. The teacher adopted the lead role in the partnership and in control of outlining the model with the scientist supporting, adding to and refining the aspects within it. Both were keen to stress the need for children to question, predict and find out, with particular interest in encouraging children to complete the process by rigorously reflecting on and interpreting their findings. They were keen to stress that children should drawn out the understandings from their observations as opposed to just accepting them. The teacher discussed that this was an area often not undertaken well, sometimes due to lack of time or due to her own lack of confidence to interpret the results further. The teacher and scientist focused on talking reflectively with the children about what had happened in their investigations and why. It was notable in this case study that the enquiries were less child-centred and mainly teacher-defined.

Model 3 emerged from the largest group in the study, where 4 teachers worked with 2 scientists across 4 age phases (6-10 year olds). This model was led primarily by the scientists with the teachers allowing them to fully share their professional practice. The teachers adopted the model whole-heartedly, noting the matches between the NC requirements and the model, yet not feeling the need to be too limiting in their thinking. The model although illustrated in somewhat linear form on paper was a recursive loop of activity, where the children were encouraged to define their questions, refine them, experiment, revisit and further refine.

3.2 Emergent themes

Three key themes permeated the reflective discussions and writings from the teacher-scientist groups. Firstly, the difficulty that children found in asking ‘good’ scientific questions, which hence posed challenges to teachers who needed to help them reframe, rephrase or indeed reject initial suggestions. Notably a core requirement of the primary curriculum relates to children coming up with their own questions for investigation, and much emphasis is placed on the need to raise different kinds of questions such that a range of investigation types can be explored. What this study illustrated was that the undertaking of this is more complicated and teachers and scientists reflected on the need to dedicate good periods of time to this activity in order for the rest of the investigative work to be worthwhile.

These quotes from scientist exemplify this theme.

> *This idea of a research question, I felt, was a new idea for the students, and upon reflection, I think that Ali and I should perhaps have devoted more time to explaining both the what and the how of research questions… the process of developing a* ***testable*** *hypothesis (research question) is at the heart of the scientific method. This is also, unfortunately, one of the more difficult concepts to teach/learn and is an area that I would like to develop with the staff who have the pedagogical knowledge to couch this concept in an age appropriate way. (Materials Engineer)*

> *The session was much more open and flexible than what I expected and students had much more independence in coming up with questions... it was students themselves who were in charge of writing the questions down and all it took was a little guidance from our part and they would open a discussion among themselves and come up with lots of questions. This is crucial because in earlier stages of research, it is important to broaden our horizons of thought and not worry about the practicality... The next step, of course, is to determine how feasible it is to investigate these questions. As scientists, we study the capabilities and limitations of equipment and techniques that we think will be relevant for our investigation… This requires a lot of time and effort and we often end up tweaking our initial questions based on the kind of measurements we can perform on the facilities available. This is a very important step so we should aim to involve students in our future discussion as much as possible so that they have a much better understand of the process of developing testable hypothesis from our initial questions. (Mechanical Engineer)*

Secondly, the model of working scientifically as represented as a non-linear process, in which cycles of activity, repetition and refinement occurs emerged from both Model 2 and 3. Scientists described how their professional lives were fraught with progression and regression of ideas, repeated iterations of activity and refinement, often fraught with frustration. Such elements of working scientifically aren’t found within the National Curriculum which presents a relatively clean or clinical formula for working scientifically. In reality, what this study found was that for children to authentically *be* scientists, to adopt scientific habits of mind (Saleh & Kine 2009) they benefited from the experience of understanding through a visual framework and through personal experience the cyclical process of enquiry.

> *I was also really pleased to see that, in spite of several failed attempts, the Year 4 (IIRC) group (with their maggots) were able to rework their experimental setup to develop a test that worked. Designing and redesigning experiments are an important aspect of science and, while frustrating, each failure leads to a better experiment. (Mechanical Engineer)*

Teachers reported that time was a key issue in this respect, and that it was necessary to dedicate longer periods within the curriculum to achieve this goal. They explained the difficulties this poses when many schools priorities literacy and numeracy teaching often limiting other subjects, such as science and the humanities to afternoon sessions. Not only was more time required within the curriculum, indeed it was found that more time was required by the teachers in terms of planning and thinking about how to move the learning forward. This related to requiring time to meet with, plan and reflect with their scientist colleagues. Within regular work-life pressures it is of importance to recognise this and to consider how such time could qualify as dedicated professional development, and as such be visible to and supported by senior leaders.

Lastly, the notion of peer review emerged as a core part of the professional life of a scientist which also lacks attention with the national curriculum. Progression in scientific endeavour requires peer review in order for research to be accepted or otherwise by the wider community. This is a well-established activity that all researchers require to embrace. What this study showed was that it was feasible and beneficial for children to experience the need to present their work to their peers and develop routines of giving, listening to and appreciating informed critique. They did not find this as challenging as the adults in the group felt they initially might, and were resilient through the peer-review process. Indeed many found the experience self-stimulating and led to proactive lines of improvement of their own work. One teacher explains,

> *During the feedback session, both groups (each having focused on a different question) presented their results. The first group to present explained how they collected their results. This explanation had a significant impact on some of the Year 2 children in that they saw the accuracy of the results and the way they were collected and concluded that 'our results aren't as good and we need to do it again' (7 year old). The children had a significant conversation about how their results could be improved. For example, taking more results and 'finding the middle number' – in their view this would give more accurate results. In order to build on this, the Year 2 children teamed up with a group of Year 3 children to gather more accurate data. This was then displayed on a distribution graph.*

These key themes require further consideration and this study provides a platform from which further work can be undertaken to exemplify how such core practices can be developed within primary classroom settings, and also for them to indeed also to be critiqued by other teachers and educators. Teachers in this study were embracing of the insights and support offered to them by the scientists. Experience from this study, which continues to be explored in follow-up work, provides an opportunity to reflect on the influence of scientists working with schools in order to make more vivid and real the qualities and practices of scientists in contemporary professional settings. Of course, many other benefits also emerge from such activity, e.g. raising children's awareness of careers in science, combating stereotypes etc.

4. CONCLUSIONS

This paper reports the models of working scientifically emerging from the collaborative work of primary in-service science teachers, university research scientists and children. By deconstructing the way scientists work and exploring what they agreed to be 'ideal' ways of working the groups undertook classroom based enquiries that found children working scientifically on their own questions. Critical reflection on how such models relate and interrelate with new National Curriculum policy in England was of keen interest and has emerged to provide three key themes that could potentially enhance how policy is translated into practice. Supporting children's question posing, allowing them to embrace a cyclical process of scientific practice which is complemented by peer review are just some findings that emerge from this study. This work to some extent challenges the statutory requirements and poses the question as to whether reframing how we encourage children to work scientifically is already required. Where this is unlikely to happen it is timely that CPD informs teachers of the ways in which the statutory requirements can be achieved whilst embracing a more realistic perspective on what it means to work scientifically. Although a highly welcome emphasis is placed on working scientifically in the new version of the English NC, it is of interest to continue to promote discussion around how teachers can provide authentic experiences that will indeed lead to children embracing what it means to *be* a scientist, and as such develop the habits of mind that will hold them in good stead for ongoing study in the sciences.

It has been evident that the co-construction of learning opportunities between teachers and scientists can influence approaches to the teaching and learning of working scientifically in primary science, however these require further exploration, trialling and dissemination.

What was prevalent in the data was the strength of feeling that teachers apply to the partnerships that that they were able to forge with the scientists, a finding also identified in other projects of this type (Bianchi & Murphy, 2014). It is of interest to further explore how best to facilitate teacher-research scientist partnerships and its influence and practicalities as a sustainable model for teacher CPD. This approach seemed to allow for teachers to develop personally through a process of mentoring, collaborative endeavour and shared experience with a science specialist, a source of knowledge and skills that teachers rarely have opportunity to exploit.

It is of interest to examine in greater depth the following questions:

- How can the indicative ideal aims, models and themes emerging from this study stimulate teachers' approaches when translating new policy into practice?
- What is the impact on research scientists' professional practice of having involvement with teachers and children in schools?
- How do other countries embrace the notion of working scientifically within their curriculum statutory requirements, and do they illustrate stronger or weaker parallels with the emergent key themes from this study?

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Appendix 1: National Curriculum Statutory Requirements for Working Scientifically

Year 1-2 **(5-7 years)**	During years 1 and 2, pupils should be taught to use the following practical scientific methods, processes and skills through the teaching of the programme of study content: ▪ asking simple questions and recognising that they can be answered in different ways ▪ observing closely, using simple equipment ▪ performing simple tests ▪ identifying and classifying ▪ using their observations and ideas to suggest answers to questions ▪ gathering and recording data to help in answering questions.
Year 3-4 **(7-9 years)**	During years 3 and 4, pupils should be taught to use the following practical scientific methods, processes and skills through the teaching of the programme of study content: ▪ asking relevant questions and using different types of scientific enquiries to answer them ▪ setting up simple practical enquiries, comparative and fair tests ▪ making systematic and careful observations and, where appropriate, taking accurate measurements using standard units, using a range of equipment, including thermometers and data loggers ▪ gathering, recording, classifying and presenting data in a variety of ways to help in answering questions ▪ recording findings using simple scientific language, drawings, labelled diagrams, keys, bar charts, and tables ▪ reporting on findings from enquiries, including oral and written explanations, displays or presentations of results and conclusions ▪ using results to draw simple conclusions, make predictions for new values, suggest improvements and raise further questions ▪ identifying differences, similarities or changes related to simple scientific ideas and processes ▪ using straightforward scientific evidence to answer questions or to support their findings.
Year 5-6 **(9-11 years)**	During years 5 and 6, pupils should be taught to use the following practical scientific methods, processes and skills through the teaching of the programme of study content: ▪ planning different types of scientific enquiries 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 enquiries, including conclusions, causal relationships and explanations of and degree of trust in results, in oral and written forms such as displays and other presentations ▪ identifying scientific evidence that has been used to support or refute ideas or arguments.