

CONFIDENCE THROUGH COLLABORATION: COTEACHING AS A MODEL OF CONTINUOUS PROFESSIONAL DEVELOPMENT BETWEEN PRIMARY SCIENCE TEACHERS AND STEM RESEARCHERS

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Abstract:

This paper explores some of the experiences of primary teachers collaborating together and with research scientists and university STEM educators to develop approaches to teaching and learning the National Curriculum Primary Science curriculum (England). The paper describes findings from a funded project which drew on the approaches of coteaching developed by Murphy & Beggs (2004, 2006). As coteachers they planned, taught and evaluated events and lessons to enhance the way in which science was taught and so to improve learning. They were encouraged to experiment with different learning and teaching approaches in order to enhance children's experiences of working scientifically and to explore their own questions and wonderings. The authors discuss how the model of coteaching acts as a powerful continued professional development (CPD) opportunity that can develop in-post teachers' subject knowledge and confidence, scientists knowledge of the school curriculum, broaden and deepen children's experience of primary science and develop a heightened sense of risk taking in the primary science classroom.

1. INTRODUCTION

Science education continues to evolve as teachers respond practically to changing government policy and academic research hastens to influence it. The theory-policy-practice divide continues to remain evident and classroom practice becomes increasingly reactive to policy as assessment and accountability measures require swift response and attention by senior school leaders.

In 2011, the coalition government minister for Education in England reported on a year-long review of the English National Curriculum (DFE, 2011). The revision focused on establishing an educational approach that had at its core the aim of making our schools, and young people, become internationally competitive again and attention was paid to England learning from the best in the world.

The draft national curriculum was subject to a public consultation between February and April 2013, and a revised version was published online in July 2013. It was subject to a final public consultation in July and August 2013 (DFE 2013). The new national curriculum was then published in September 2013, for implementation from September 2014. This new curriculum for all subjects contains the essential knowledge that all children should learn, and

government was clear in its intent to state that this would not dictate how teachers should teach.

Implementation guidance provided by Department for Education for teachers, in terms of support for the teaching of science, focused on the use of the National STEM (Science, Technology, Engineering and Maths) Centre resources for primary and secondary science and attention is drawn to the 'Practical Science' resources (2013) which aim to strengthen science practical work albeit it only for secondary schools and colleges. Support for teacher continuous professional development is provided by the National and Regional Science Learning Centres, Local Authorities, publishers, educational charities, independent consultancy groups and individuals, initial teacher training and other University-based education organisations, on-line providers and school-to-school support.

These providers aim in the main to enhance teacher's competence and confidence in a wide variety of areas, such as science subject knowledge, classroom pedagogy, assessment practices, subject coordination and subject leadership. Primary Science teacher confidence and its effect on practice has been an area of interest for some time (Harlen, 1995; Appelton 1997; Harlen & Holroyd 1997; Murphy & Beggs 2005; Murphy et al. 2007). Influencing teacher confidence however continues to be a challenge, as noted by OFSTED (2011) in their evaluation of school science between 2007-10.

Murphy & Beggs' (2005) Scoping Study for the Wellcome Trust identified that teachers felt 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. Indicative evidence provided by teachers aligned with the authors curriculum development activity signifies that the same issues still prevail, and the situation in schools may in fact have worsened since that reported in 2007, since the removal of primary science standard assessment tasks (SATs).

The removal of SATs was predicted by some to potentially improve the type of science learning being undertaken by children, with greater leanings towards investigative science (Collins et al, 2008). Evidence remains divided, however, as to the true impact of this change and what has resulted in many cases is the lowering of the status of science (Wellcome Trust, 2011).

Primary teachers' confidence to teach knowledge and skills in primary science is the focus of this paper. It reports on a 12-month curriculum development project in which primary teachers, secondary teachers and STEM researchers co-constructed and co-taught learning opportunities for junior aged children. A coteaching approach was integrated into the methodology and involved a collaborative process of planning, teaching and reflection (Murphy & Beggs 2009). The paper focuses on the effect of this approach on teachers' confidence and reflects on the approach as a model for continued professional development for new and in-service teachers and asks, 'What effect does a co-constructed approach to curriculum development have on the teachers' confidence to teach knowledge and skills in primary science?'

Coteaching occurs when teachers share the responsibility for all aspects of students' learning during an instructional time frame (e.g. a class or curricular unit), including planning,

teaching, assessment and evaluation (Martin, 2009). Coteaching has been applied to science teacher education in both the preservice and inservice settings, and its usefulness as a model for learning to teach has led to its expanding use in other content areas and educational settings (Murphy et al. 2013). It provides a structure for teacher reflection on theory, praxis and practice and has been shown to address a variety of issues in science education including teacher planning, the quality of teacher pedagogical knowledge and pedagogical content knowledge, formative evaluation of student learning, and professional practice and self-efficacy. Coteaching promotes a sense of shared responsibility for teachers (Wassell & LaVan, 2009) and increases access to social and material resources, thereby increasing opportunities for classroom actions (Roth et al., 2004). In addition, coteaching and the subsequent need for coplanning among teachers, nullifies teachers' common practice of isolated planning. While many teachers plan lessons in isolation, and prefer to do so, such practice typically results in maintaining current teaching practices, rather than changing lessons to meet students' differing needs. When teachers plan collaboratively and coteach those lessons, they have more opportunities to respond to the learning needs of diverse students (Thousand et al, 2006).

2. METHODOLOGY

This paper reports on a research project that aimed to create National Curriculum-linked schemes of work/topic plans that were stimulated by, and permeated with children's wonderings about the world. The project combined CPD using coteaching partnerships between primary and secondary teachers and university STEM educators, focused on enhancing teacher's confidence in chemistry and their skills in working scientifically. A key aim was to authentically respond to children's scientific wonderings and questions. Inspiration came from the exploration of the centrality of wonder in teaching and learning across the curriculum, work being undertaken by groups aligned with the Imaginative Education Research Group in Vancouver (Egan et al, 2014) and from the 'NASTA – new approaches in science teaching and assessment' (Murphy et al, 2009) and 'SCITE – Science Coteaching in Teacher Education' projects (McCullagh, Doherty and Murphy, 2013). Insights from this research endorsed the project's interest in sharing professional practice and co-developing understandings through curriculum development and classroom based activity.

2.1 Context

Of the group (n=12) who all taught in urban/suburban localities, four had been teaching for less than five years, four between 5-10 years, three between 11-20 years and one over 20 years. They were all teachers of 7-11 year olds and some held senior leadership positions – four being subject leaders (of which two were also Assistant Head teachers) and one was a Deputy head teacher. Only three out of the 11 who completed the questionnaire had previously carried out any professional development or research/project work in science education, and those who had had experienced it only through prior involvement in the author's previous studies. The teachers, in the main, reported teaching science for 1-2 hours per week, with only two teaching it for less than 1 hour per week.

Factors the teachers identified as being the main issues they faced in their science teaching were lack of: time, perceived lack of subject knowledge, equipment and resources. In comparison to other subjects, teachers rated their confidence generally to be as good as in other subjects when self-rating at the beginning of the project (1 = very low to 5 = very high scale).

2.2 Interventions

Seven schools (five primary and two secondary) and three university groups involved, in total: fourteen teachers, five research scientists and engineers, two project leaders, approximately 270 children and three science educators. The CPD events were facilitated and planned by a lead science educator/project manager. The methodology involved an immersive learning programme that comprised of cycles of CPD and reflection events, followed by periods of school based activity. In total there were two development days, a three-day blocked Immersion Event, a half day review meeting, in-school activity including sharing practice with others through school assemblies, display and staff meetings, and a celebration pupil conference.

During the development and Immersion Event days, teachers shared insights into the pedagogical approaches used to engage children in learning science in the primary classroom. Scientists and science educators whose expertise lay in general science, chemistry and atmospheric chemistry/climate change shared knowledge and understandings around the core principles related to the nature of matter and chemical reactions. The project was targeted at enhancing the teaching of chemistry as defined by the 1999 Key Stage 2 English National Curriculum Programmes of Study (pupils of 7-11 years of age). Practical activities, experiments, analogies and models formed key parts of developing the knowledge and understanding of the teachers. The stimuli provided shared experiences between the primary teacher-secondary teacher-researcher-educator partnerships.

Coteaching was encouraged throughout the whole experience with teachers and researchers encouraged to group together to plan, teach and reflect collaboratively and critically. Project leaders designed activities to incorporate practical science experiences and also encouraged teachers and researchers to share time in informal, non-taught parts of the development days. All groups planned schemes of work/topics for up to 8 weeks of study which were taught for 2-3 hours per week. Lessons were undertaken in classrooms, outdoor spaces and High school laboratories. Each school/scientist partnership group regularly presented progress to project peers and in their schools, focusing on the progress and impact of the work on children's learning, the teacher-scientist partnerships, and on themselves. During the celebration conference children presented their learning to a wider school audience including senior leaders, school governors, parents and representatives from the funding charitable organisations.

2.3 Data Collection

Research methods used to catalogue and record teacher and scientist experiences and perceptions included pre and post teacher confidence questionnaires (as used in Murphy & Beggs 2005), videos, project leader reflective notes from informal meetings, curriculum plans and reflective letters. Videos of one-to-one interviews were taken during the Immersion Event with participants using a SWOT model to reflect (strengths, weaknesses, opportunities and threats). Participants wrote reflective letters at the end of the project which focused on messages to themselves at the start of the project. These were written independently and were only shared with the project leader.

Data from the reflective exercises was collated, transcribed where necessary for evaluation purposes. What emerged were findings that surpassed what was usually expected of a CPD course. As such these were of particular interest for the project leader and funding groups (namely the Primary Science Teaching Trust and the Comino Foundation). In order to

further understand this data, the questionnaire results, reflective letters and video recordings have been reviewed in greater detail, and key themes drawn out. In particular such data sets have been analysed to explore the influence of the project on the:

- nature of coteaching practice within the teacher-research scientist groups
- development of teacher's confidence in Chemistry subject knowledge.

3. FINDINGS AND DISCUSSION

3.1 The nature of coteaching practice within the teacher-research scientist groups

Coteaching consists of coplanning, copractice and coevaluation. Within the project primary teachers were brought together with research scientists and high school partners where possible. Immersion and development days provided opportunity for the project leader to facilitate activities and structure experiences that enabled participants to share experiences, develop relationships and explore each other's professional roles. No specific training on coteaching was provided to the teachers or scientists, yet it was used to guide the model of practice that the project leader used to coordinate the activities/development opportunities for the group. Encouragement was given by the project lead for small groups to form consisting of up to 3 primary teachers, 2 high school teachers and a research scientist. These groups spent a good proportion of time during the Immersion event building relationships, finding out about each other's work practices and planning topics of work. The topic plans brought together children's questions, core aspects of desirable learning from the primary Science National Curriculum and interventions that supported the development of science knowledge in interesting or innovative ways.

Discussions during the Immersion event and in subsequent meetings were lengthy and the project lead allowed time for sharing and refining ideas with the whole project group. Where it was thought useful researchers were able to source equipment to demonstrate practical activities that could link to the plans of work, and teachers provided rigorous insight into the curriculum and pedagogical implications within their own contexts and school settings. The planning included outlining dates, times and required resources, such that the school based activity would start relatively quickly after the Immersion and development days.

Each school-researcher partnership produced detailed planning which teachers took the lead on, using standard school based planning grids to log activity. The groups liaised using electronic mail and telephone in between face-to-face meetings and partnerships were in general proactive and responsive. There was no minimum or maximum time obligation for the project by any group other than the face-to-face meetings, yet there was an explicit overarching expectation to be innovative and to extend children's learning to its fullest.

Copractice, whereby teachers and researchers delivered lessons together, took place in a range of ways. In some cases, where a research scientist was unable to attend or distance from the school locality hindered the opportunity to collaborate, high school teachers adopted the same type of roles. The interplay between teachers and high school teacher/researcher scientist was found to be:

- research scientist teaching teacher about an aspect of science, through practical exploration, drawings, modelling and questioning
- teacher teaching research scientist about the school curriculum, effective teaching strategies and pedagogies

- primary teachers undertaking preliminary lessons prior to researcher visits to the primary school, so as to establish where the children's understandings lay or lessons that followed on from a researcher-involved experience
- high school teacher/researcher leading a particular science-based practical with primary teacher mediating language and breaking down activities into manageable steps for the children
- primary teacher leading activities that had been coplanned with the research scientist, but the researcher was not present
- research scientist undertaking an assembly, demonstration with no intervention from the primary teacher
- high school teachers delivering lessons for primary children who visited their school laboratories.

Teachers explain the impact of such collaborative practice.

Kate (primary teacher: 9-month-on written reflection)

[I] cannot stress how important [the link between researchers and teachers] was to have an increased confidence in [my] own subject knowledge. Like the collaborative planning, how fab is it to be able to tap into the expert's way of doing things?... Also it's nice to build up relationships with people who can come into the classroom and help.

Gemma (primary teacher: video)

The strengths of the project ...it's been really lovely planning as a four – as a chemist, a secondary school Chemistry teacher and then there's myself and my colleague, primary school teacher. And that mix today has been coming out as really important and really strong. The Chemist having such amazing chemistry knowledge and Alison, being a lovely bridge between the Chemistry and the teaching aspect and then Louise and I have the primary pedagogy. I think I've really seen that in action today, working well.

(Alison, secondary teacher. video)

Tim [the Chemist] ... was able to explain them to the primary school teachers and the other scientists were... and give them other ways of explaining, for instance particle theory. They were really confident in explaining, and it was nice to see that.

Jake (primary newly qualified teacher: video)

... it's not very often you get chance to work with specialists to develop something you can do with your kids. If I'm truthful its inspired me more being here and actually doing it and thinking 'I can do that' I can do this – and it's not actually that much to get a candle out in a lesson or that much to use some chemicals as long as you explain it to the children, explain what you're doing. So it's given me a confidence in that sense to go to my classroom and have a go. And it's also been nice, not just people in their field of Chemistry, but experienced teachers who've then gone 'perhaps you could do it that way' or 'have you thought about doing this' so it's been quite nice from a personal point of you.

Coreflection was a facilitated activity that the project leader supported. Particular directed tasks were undertaken, such as teachers and researchers undertaking short presentations to the main group to explain activity and impact, the video 'talk-to-camera' activities and the reflective letter. Reflections on individual lessons/aspects of the learning seemed to emerge less strongly, with most teachers and researchers providing general impressions of activity. In hindsight a more concerted effort to encourage coreflection activities soon after the delivery of an experience would be useful in truly understanding the limitations and

successes of particular styles or approaches to teaching and learning, as well as deconstructing the nature of the collaborative teacher-researcher relationship.

Whereas the teacher responses indicate the benefits of the collaborative relationships, none made reference in their reflective letters or video commentaries of the practical issues arising from organising and sustaining such involvements. Previous studies have noted the influencing factor teacher-coteacher relationships as being an important factor in the success of coteaching (Murphy & Beggs 2005), which in this study relied on a matching being directed by the project manager during facilitated activities during meetings and the Immersion event. On such occasions dedicated time was given to relationship building, sharing practice and learning experiences as well as coplanning and coreflection. The main breakdown or limitation on the copractice in schools was found less to be to do with personal relationships and more to do with availability of time and the distance between the school and the researcher.

What proved apparent across the school-researcher groups was the range of approaches of copractice that took place in the classroom. Teachers discuss how the project has helped them experience science which in many ways was 'led' by children's interests, and indeed their own. There was a change in teacher attitude and practice to science teaching resulting from feeling supported and having shared responsibility and ownership for their lessons. Such findings relate to those reported by Murphy et al (2013). The range of interpretations for copractice provide a rich insight into what can be feasibly achieved in such circumstances, especially where a non-teaching and non-school based professional is involved in the partnership.

This study adds to the literature on the implementation of coteaching in schools and supports the discussion that coteaching leads to transformative practice (Murphy and Carlisle 2008; Tobin and Roth 2005) by providing expanded opportunities for diversifying teaching and learning styles through shared contribution, collective responsibility and the active promotion of each other's agency (Murphy and Carlisle 2008). It provides new insights into how this model can also be applied to copractice relationships across professional disciplines where the focus of development is the enhancement of learning opportunities in primary science, and stimulates further research interest to explore the impact of such practice on the research scientists' professional and personal development.

3.2 The development of teacher's confidence in Chemistry subject knowledge

The project activities, in particular those undertaken in the three-day Immersion Event, focused on developing subject knowledge and skills in Chemistry with key focus paid to the concepts of the Nature of Matter and Chemical Reactions.

Teacher expressed apprehension and concerns over their own subject knowledge.

Gemma (primary teacher: video)

Weakness of mine that I have realised, is basically my science knowledge, just not knowing enough about things, so you think OK I can explain this at a primary level but you realise actually you personally need to know at a deeper to really explain it at a primary level...you start grasping some understanding of... OK I see where that goes, and it helps with the more basic level.

Louise A (primary teacher: reflective letter)

The worries that you have about your own chemistry subject knowledge will be addressed at the Immersion Event, where you will have the opportunity to ask all the questions you need, as many times as you need.

Louise B (primary teacher: reflective letter)



... as you are well aware, your subject knowledge is currently woeful and because of that science is a weekly necessity rather than something to look forward to.

Project teachers' rated their confidence to develop children's understanding of areas of Biology, Chemistry and Physics, as shown in Table 1. In general, post-questionnaire data illustrates a general positive shift in confidence across three out of the four areas of work in Chemistry, namely those that were addressed within the Immersion event. It is also notable that perceived confidence in other aspects of science has also changed, yet the greatest number of 'very high' responses relate to those related to Chemistry.

Scaled responses	Number of teacher responses												
	Biology		Chemistry				Physics						
	basic life processes	life cycles of a flowering plant	properties of solids, liquids and gases	the water cycle	permanent/temporary change	renewable/non-renewable energy sources	investigating circuits	insulators and conductors	how sounds are produced	friction	how sound travels	reflection of light	how we see things
Very low 1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	3	1	3	2	2	3	2	2	0	2	3	2
3	2	2	4	0	3	2	4	1	3	6	2	1	2
4	5	3	4	5	5	5	2	6	4	4	5	5	5
Very high 5	0	1	1	1	0	0	0	0	0	0	0	0	0
No response	2	2	1	2	1	2	2	2	2	1	2	2	2

Scaled responses	Number of teacher responses												
	Biology		Chemistry				Physics						
	basic life processes	life cycles of a flowering plant	properties of solids, liquids and gases	the water cycle	permanent/temporary change	renewable/non-renewable energy sources	investigating circuits	insulators and conductors	how sounds are produced	friction	how sound travels	reflection of light	how we see things
Very low 1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	0	0	0	1	0	1	0	0	1	0	2
3	2	1	0	2	2	3	6	3	6	4	4	5	4
4	5	7	4	5	2	5	2	3	3	5	4	4	3
Very high 5	1	1	6	3	6	0	1	2	0	1	0	0	0
No response	2	1	1	1	1	2	2	2	2	1	2	2	2

Table 1: How would you rate your confidence (1-5) in developing children's understanding of the following areas from 1 = very low to 5 = very high

-  Decrease in self rating score
 Increase in self rating score

Teacher's qualitative reflections provide contributory evidence of their increased sense of confidence to develop children's understandings. Reference is made on a number of occasions to the Immersion Event being a key event in their professional development.

Jake (primary newly qualified teacher: written reflection)

It was great to hear how scientists approach different aspects of science and build links... [It's] improved my subject knowledge and restarted my interest in science. It has made me consider doing more science CPD... I feel more confident in teaching the science... I felt I was good at science but I wasn't a good science teacher. Since the course I am not afraid to have big experiments and teach science the way I would want to learn it... Chatting with the experts gave me confidence in my scientific understanding and allowed me to think more about how to teach in an interesting way.

Suzanne (primary teacher: email reflection)

The 3 days were great! When I was telling colleagues about it, it struck me even more how enjoyable and challenging it had all been and how rarely we get the opportunity to talk and work and think in such depth about one area of teaching.

Ross (primary teacher: reflective letter)

By the end you will have broadened your own knowledge of science and will also feel much more confident in teaching it is a more creative and exciting way, you will also have some wonderful ideas from all those you have worked with.

Opportunity for primary teachers to be involved in training or subject development for science is limited, and relies most significantly on initial teacher training course, in-service training led by subject leaders in school, a local authority or external training provider. Professional support of this kind for primary science has declined since school leaders have found it increasingly demanding to improve standards in Literacy and Numeracy, and as the status of science in primary schools has declined since the removal of standard assessment tasks. Funding allocated to science professional development is also limited in most schools, with subject leaders have discussed in general discussions having overall budget for science resources and development to the order of approximately £300 per annum.

This study illustrates an approach to primary teacher continued professional development that spans the course of an academic year (9 months), is facilitated and overseen by a University based project manager with specific expertise in primary science curriculum development and involves research scientists. The model relies on two teachers working together from each primary school and for pupils' interests to be acknowledged and act as a core focus of interest. This contrasts to more typical one, two or three-day courses offered by a training organisation/institution.

Teachers in this study, although initially apprehensive and lacking in confidence about their own science knowledge and understanding, were embracing of the support offered to them. By learning experientially through practical activities, the teachers developed confidence as they shared both the 'magic' of the science, and felt supported in understanding the reasons for the phenomena. Having dedicated time out of school with specialist support of both a project manager and research scientist relied on funding. Such features of CPD are challenging in terms of sustainability, although many UK Universities offer Outreach and Widening Participation programmes that would provide primary school teachers with access to activities, such as workshops, events and visits that could support the delivery of the science curriculum. Experience from this study, which continues to be explored in follow-up work, provides an opportunity to reflect on the impact of such longer-term partnerships on children's learning, teacher's confidence in teaching science and latterly how such work can impact on at a whole school level in terms of increasing the status of primary science. For this to be achieved a more focused study with research methodologies targeting each area of interest will be required.

4. CONCLUSIONS

The focus of this paper reports on the coteaching experiences specifically in terms of its effect on teacher's confidence to teach knowledge and skills in Chemistry as part of the primary science school curriculum. It explores the way in which, through a facilitated

project, teachers and researcher scientists were brought together to develop, deliver and reflect on projects that they created in response to primary children's questions. Over the course of an academic year they engaged in a key CPD three-day Immersion Event, as well as other development activities.

What has been prevalent in the data presented was the strength of feeling that teachers apply to the partnerships that they were able to forge. They outline the new and richer opportunities that they felt they were able to achieve as they drew confidence through the partnership activity with research scientists. The coteaching approach, although it could be argued aspects of which could be enhanced in future, provided a *modus operandi* where professional skills and knowledge could be shared and developed. A sense of team-ness and togetherness was sensed that teachers relate as increased confidence and excitement to push the boundaries of the curricula that they regularly deliver.

Although it is acknowledged that this paper grows out of a curriculum development project, and one where a more rigorous research approach could be applied if it were to be replicated, it is evident that further understanding about how best to facilitate teacher-research scientist partnerships is of interest. As a model for teacher CPD what this approach provides differs from standard one-day or short 'courses', where the development of activities is often predefined and not responsive to children's questions from the classroom. This model allows 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.

Financial support from funding bodies has been crucial in enabling this type of activity to take place. Support for teacher's time out of school, by way of paying supply cover, resources and general expenses has been required. Whether this is from school or funding bodies, it is important to acknowledge this investment.

It is of interest to research in greater detail the influence of an immersive, collaborative approach to Primary Science teacher CPD, and to examine in greater depth the following questions:

- How does a coteaching approach influence the development of primary science teacher identity?
- What funds of knowledge are available to support the development of primary science teacher identity?
- How can the coteaching approach support the personal and professional development of the research scientist/high school teacher?
- What is the role of research scientists in the enhancement of science teaching and learning in schools?

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References

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

Collins, Reiss & Stobart (2008). *The Effects of National Testing in Science at KS2 in England and Wales*. London: Wellcome Trust.

Department for Education (2011) *Framework for the national curriculum: a report by the expert panel for the national curriculum review*. Available at <https://www.gov.uk/government/publications/framework-for-the-national-curriculum-a-report-by-the-expert-panel-for-the-national-curriculum-review> [Accessed 1.7.14]

Department for Education (2013) Schools and Colleges Curriculum and qualifications. Available at <https://www.gov.uk/schools-colleges/curriculum-qualifications>. [Accessed 1.7.14]

Harlen, W. (1995) *Understanding and teaching science*. SCRE newsletter no. 57 (Glasgow, Scottish Council for Research in Education).

Harlen, W. and Holroyd (1997) *Primary teachers' understanding of concepts of science: impact on confidence and teaching*. International Journal of Science Education, 19/ 1, 93-105.

Letter from Rt Hon Michael Gove MP to Director of Research & Assessment (11th June 2012). Available at <http://webarchive.nationalarchives.gov.uk/20130904095348/https://media.education.gov.uk/assets/files/pdf/1/secretary%20of%20state%20letter%20to%20tim%20oates%20regarding%20the%20national%20curriculum%20review%2011%20june%202012.pdf> [Accessed 1.7.14]

Murphy, C. and Beggs, J. (2005) *Primary Science in the UK: a scoping study*. Wellcome - London. Available at http://www.wellcome.ac.uk/stellent/groups/corporatesite/@msh_peda/documents/web_document/wtx026636.pdf. [Accessed 1.7.14]

Murphy, C., & Carlisle, K. (2008). Situating relational ontology and transformative activist stance within the 'everyday' practice of coteaching and cogenerative dialogue. Cultural Studies of Science Education. doi:10.1007/s11422-008-9124-y.

McCullagh, J., Murphy, C., & Doherty, A. (2013) The preliminary findings of the Science Coteaching in Teacher Education (SCITE Project): The student teachers' perspective. Presentation at the Irish Association for Social Scientific and Environmental Education annual conference, Dublin.

Murphy, C., Neil, P. & Beggs, J. (2007) *Primary science teacher confidence revisited: ten years on*, Educational Research, 49-4, 415-430.

Murphy, C., Carlisle, K. & Beggs, J. (2009) *Can they go it alone? Addressing the criticisms of coteaching*. Cultural Studies of Education, 4:461–475 DOI 10.1007/s11422-008-9150-9.

Murphy, C. and Scantlebury, K. (2010) *Coteaching in International Contexts: Research and Practice*. Dordrecht, Springer. ISBN: 978-9048137060.

Murphy, C., Bianchi, L., McCullagh, J. & Kerr, K. (2013) Scaling up higher order thinking skills and personal capabilities in primary science: Theory-into-policy-into-practice. Thinking Skills and Creativity (2013), <http://dx.doi.org/10.1016/j.tsc.2013.06.005>

National STEM Centre (2013) *Practical Work: Resources for teachers and technicians for practical lessons*. Available at <http://www.nationalstemcentre.org.uk/sciencepracticals> [Accessed 1.7.14]

OFSTED (2011) *Successful Science*. Available at <http://www.ofsted.gov.uk/resources/successful-science>. [Accessed 1.7.14]

Standards and Testing Agency (2014) *National Curriculum Assessments: assessment and reporting arrangements – Key Stage 2*. Available at

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/278150/2014_KS2_assessmentandreportingarrangementsARA_DIGITAL_HO.pdf. [Accessed 1.7.14]

Tobin, K., & Roth, W.-M. (2005). Implementing coteaching/cogenerative dialoguing in an urban science education. *School Science and Mathematics*, 105, 313–322.

Vygotsky, L. S. (1981). The development of higher forms of attention in childhood. In J. V. Wertsch (Ed.), *The concept of activity in Soviet psychology*. Armonk, N.Y.: Sharpe.

Wellcome Trust (2011) Primary Science Survey Report, December 2011.

http://www.wellcome.ac.uk/stellent/groups/corporatesite/@msh_peda/documents/web_document/wtvm053596.pdf. [Accessed 8.7.14]