Critical reviews of an area of literature

The Role of Subject Knowledge in the Effective Teaching of Primary Science

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Contextualisation

To teach science in a contemporary primary school requires more than a sound knowledge of science. Being able to explain science in a way that is accessible, relevant and inspires interest and confidence among pupils are also other key factors. The review paper that follows examines the literature around some of these issues.

Abstract: *Teachers' own subject knowledge and understanding in science is considered by many to be the key factor determining their effectiveness as primary science teachers. This paper argues that whilst teachers' subject knowledge and understanding is important, the picture is complex, as many other factors are also involved. Thus the response to ineffective primary science teachers should not simply be to send them on professional development courses to enhance their subject knowledge and understanding. The context of the research for this paper is a longitudinal study investigating how primary teachers engage with science in the classroom and the factors that contribute to their patterns of engagement.*

Introduction

> "If he had only learnt less, how infinitely better he might have taught much more"
>
> Charles Dickens (1854)

So thought Mr M'Choakumchild, the newly qualified teacher in Dickens's Coketown.

Mr M'Choakumchild had, with many others, recently been turned out "like so many pianoforte legs" from college. He had successfully answered "volumes of head breaking questions" on a wide variety of subjects from algebra to the "Water sheds of all the world (whatever they are)".

But despite this learning, he did not feel that he was adequately prepared for the task of teaching the pupils of Coketown, there was clearly something missing from Mr M'Choakumchild's training.

This paper explores the factors, including teachers' own science subject knowledge and understanding, that contribute to teacher effectiveness in primary science.

Reports from government agencies on the role of subject knowledge and teacher effectiveness

The importance of primary teachers' own subject knowledge and understanding in the successful teaching of science has been a central theme in documents from government agencies before and since the introduction of the National Curriculum in 1989. It is central to the 1998 Initial Teacher Training National Curricula in England and Wales (DfEE, 1998). In

1978, the DES identified teachers' lack of subject knowledge and understanding, as the "most severe obstacle" to the improvement of primary school science.

In the year in which the National Curriculum was introduced in primary schools the HMI report on primary science in 1989 stated that opportunities were needed for teachers to:

> …improve their own knowledge of science in relation to what children should know, understand and be able to do.
>
> (DES para 100, p 25)

Nine years later this view was supported in the Office for Standards in Education (Ofsted) report of 1998, which stated that:

> …steps need to be taken to enhance the science subject knowledge of teachers, especially those teaching older classes.
>
> (Ofsted, para 1, p 5)

The Ofsted report suggested that teachers lacked knowledge and understanding of particular areas of science, especially the physical sciences, and that this lack of understanding led to an overemphasis in their teaching on knowledge acquisition at the expense of conceptual development. In their report, Alexander et al. (1992) recommended that in-service training (INSET) for teachers should be "more exactly targeted on the issue of improving subject expertise". The situation relating to teachers' confidence in their ability to teach science in the primary school appeared to have improved by 1998/9. Few teachers were said to lack confidence in teaching science, but this was still identified as the reason for the small gains made by their pupils:

> Gains have been smallest where the few teachers who continue to lack confidence in science have relied on merely giving information and have not engaged the interest of pupils through lively exposition or stimulating practical work.
>
> (DfEE, 2000, para 16, p 4)

This underlying assumption that subject knowledge is the most important factor is treated as unproblematic in many contexts. A review of recent research into teacher subject knowledge and understanding will show that whilst it is very important, it is not necessarily the most important factor in determining teacher effectiveness. Its role is, to say the least, more uncertain than suggested by the official reports. The literature shows that even when teachers have a firm grasp (cognitive grip) of the relevant subject knowledge and understanding, effective teaching is not automatically guaranteed. The picture is more complex. Whilst the research examined for this chapter concentrates on primary science, research involving other areas of the curriculum, such as music and mathematics, has also been explored.

Research evidence on the influence of 'subject knowledge and understanding' on teacher effectiveness

The following two examples from primary classrooms explore the influence of 'subject knowledge and understanding' on teacher effectiveness. They both show that the more effective teacher was the one with the higher qualification in science. Whitby (1993) examined the relationship between teachers' confidence to teach primary science and their knowledge and understanding of science subject matter. She showed that the teachers' confidence to teach science was determined by their own science subject knowledge and understanding, and that this in turn influenced their teaching style. Whitby observed the science lessons of two Key Stage 1 teachers, A and B, both considered by their headteacher to be good practitioners. Teacher A had a science degree and expressed a confidence in teaching science to young children. Teacher B felt that her own science knowledge and understanding was very limited, and that this led to a lack of confidence to teach science to young children, but she regarded science as an essential part of the primary curriculum. The two teachers collaborated on their planning and both classes did the same activities. Whitby focussed on the questioning techniques of the two teachers. She found that teacher A asked more questions and that her questioning led to the problem being solved. Teacher B, on the other hand, asked fewer questions, her questioning led to confusion and she ignored suggestions made by the children. Teacher B said that she rushed the activity to prevent the children asking questions that she could not answer. Whitby concluded that it was teacher B's poor science subject knowledge and understanding which led to her lack of confidence to teach the science content of the lesson, and that this undermined the learning in classroom B.

Whitby does not tell us how it was determined that both teachers were good practitioners, nor if what she observed during this one lesson was typical of how the two teachers taught. However, teacher B cited her lack of science subject knowledge and understanding as determining her teaching style, i.e. poor questioning and avoidance of the children's questions.

Brown and Simon (1996, cited in Osborne and Simon, 1996) observed two primary teachers teaching the topic ‘light’ to lower Key Stage 2 (7-9 year-old) children. Carol, a linguist, reported that she lacked confidence to teach science, saying of herself "I like science, but I am not a science person". She felt vague about her science teaching plan and was unsure about what she was trying to achieve. Carol used a variety of source materials to plan activities for the children and to extend her own subject knowledge and understanding. Fiona, a science graduate was confident in this subject, ‘light’. She set out to teach the same National Curriculum Programme of Study as Fiona: i.e. 'light can be reflected and that reflection of light enables objects to be seen'. Carol's plan matched relevant activities for the children to the important concepts of the topic. The questioning style of the two teachers was different. Carol attempted to discuss how we see an object with her class, but her rapid questioning and hint that the concept was difficult, rendered the children mute. Fiona had a more open style of questioning. Unlike Carol, she had a clear picture of the direction of the discussion, but was able to make use of the children's ideas. When asked 'how we see', seven out of ten of Fiona's children were able to give an acceptable answer, whereas none of Carol's children were able to do so, although five out of nine of them could describe how they saw their reflections in a mirror. Brown and Simon concluded that the children's responses were linked to their teachers' level of confidence in their discussions of 'how we see objects'. Carol's children were able to describe how we see our reflection in a mirror, because she was confident in this area of knowledge and understanding.

In both studies, the teacher with a higher level of science subject knowledge and understanding in science – i.e. a science degree – was a more effective teacher of science. This observation is hardly surprising, a science graduate would be expected to have a strong interest in science and as a teacher a strong interest in science education: indeed Fiona was the school's science coordinator. Contrasting the success of science graduates against the poorer performance of teachers with little or no science in their backgrounds is not particularly helpful, as these two positions are the extremes in a primary school. As neither study indicated what science degree the successful teacher had, we cannot be sure how relevant it was to the science topic that the teachers were teaching. We were not told if Fiona's degree was biology, chemistry or physics based. It is possible to study biology successfully to degree level, with no qualifications in physics. Fiona's effectiveness in teaching the physics based topic, light, may have been more to do with how she understood what she knew, rather than how much she knew. As Shulman (1991) argues, the effective teacher must be able to build bridges between their own understanding of subject matter and that which their pupils develop. Fiona may have had a good understanding of what her pupils already knew and so she was able to tackle their misconceptions and to ensure that the 'new' science that she was teaching allowed the pupils to challenge what they already knew.

Research into the level of teachers' subject knowledge in science: the 'deficit' model

There have been several research projects looking at the level of teachers' subject knowledge in science. The findings of these projects are that the teachers are deficient in subject knowledge and so are less effective teachers of science. Symington and Hayes (1989) and Tobin and Garrett (1988) supported the views of the Ofsted reports quoted above. For them, the lack of necessary content knowledge had important implications for helping primary teachers to improve their practice.

A Leverhulme project in 1989, at the University of Exeter, surveyed 901 teachers across 51 primary schools, to ascertain the teachers' perceptions of their competence and needs with respect to the new National Curriculum in the UK. Thirty four per cent (34%) of the teachers felt confident in their existing knowledge and skills, in science. This placed science eighth out of the ten primary subjects that the teachers felt competent to teach. These results are perhaps not surprising, as only eight per cent of the teachers had specialised in science in their own higher education. The results for the other subjects followed a similar pattern; i.e. the teachers' confidence was linked to their subject specialism. Carré and Carter (1990), who carried out the research, were not attempting to verify the teachers' level of understanding: that is, there may be a mismatch between what the teachers say that they know and understand and what they actually understand. Overall, many primary teachers rate their competence to help pupils to achieve science process skills quite highly, but a large number indicate that they need a good deal of professional development support for further development of scientific knowledge, especially in the physical sciences.

This research was followed up two years later in 1991, when the National Curriculum was in its second year. Of the 433 teachers surveyed for the project, forty one per cent (41%) now felt competent with their existing science knowledge and skills. Thus science moved from eighth place in 1989, to third place in 1991. What had happened in these two years to account for the rise? For Carré and Carter (1993) the "precise reasons for these changes are beyond the scope of this enquiry". They concluded that, "science teaching in primary schools will have been substantially enhanced by the advent of a national curriculum if these data can be generalised". Thus, teachers had taught National Curriculum science for two years, so experience led to increased confidence. In 1989, the teachers underestimated their competence with their existing science knowledge and skills. By teaching National Curriculum science they realised that they knew more science than in the pre National Curriculum era.

Bennett and Carré (1991) looked at the role of subject knowledge and understanding in PGCE student teacher effectiveness. They compared music lessons given by music specialists and non-specialists. The analysis of the lessons showed that "not only do the specialists maintain a much better balance between teaching and management, they do so at consistently higher levels of performance". Bennett and Carré concluded "subject knowledge is a vital ingredient in high quality teaching and pupil learning, and that teachers "cannot teach well what they do not know". Bennett and Turner-Bissett (1993), continuing this area of work, wanted to find out if student teachers taught their specialist subject to 7-11 year olds to higher levels of competence than their non-specialists. They looked at the performances of primary teachers whose specialisms were music, science or mathematics, and how well they taught their specialism and non-specialism. The researchers found that the music specialists taught music to a higher level of competence than the mathematics and science specialists taught mathematics and science. The music specialists had a higher level of subject knowledge and understanding in music than the mathematics and science student teachers had in their respective specialisms, mathematics and science. It was concluded that having a higher level of subject knowledge and understanding results in the student being able to teach to a higher level of competence. Hence the music specialists were more successful at teaching music than the science specialists were at teaching science, and the mathematics specialists were in teaching mathematics.

There has been considerable research showing that teachers lack conceptual understanding in many areas of science (Smith and Peacock, 1992; Kruger, Palacio and Summers, 1990; Summers and Mant, 1995). The response to the results of this type of research has been used to develop professional development materials in order to remedy this apparent deficiency, rather than question the extent to which it matters. Others, however, have argued that focusing on teachers' understanding of science subject matter exaggerates the extent of the problem. If teachers appreciate in a general sense the nature of science, then they can engage pupils in enjoyable science activities. Golby, Martin and Porter (1995) make this point in their critique of the work of Mant and Summers (1993) on the lack of primary teachers' knowledge and understanding of 'the Earth's place in the universe'. They describe Mant and Summers as having a transmission view of teaching, with an implied reception view of pupil learning. For this mode of teaching the teacher must have a sound knowledge base to enable them to pass on their learning to the pupils. Golby et al. said, "teaching is not principally about telling facts, but about finding meaning in experience". This position implies that teachers do not need such a high level of subject knowledge and understanding. While the critique of Golby et al. is useful in indicating the complexity of the issue, they leave unexplored the question of how the teacher is to select those experiences in which the pupils will find meaning and how the teacher will help the pupils to find that meaning. Not surprisingly Mant and Summers refute this criticism of their work. They argue that they have a constructivist view of learning in science, and that their professional development materials reflect this. They strongly support the view that having a sound subject knowledge and understanding of science is an important condition for being able to teach it well (Mant and Summers 1995). McDiarmid, Ball and Anderson (1989) in their study of teacher knowledge reported that teachers' own subject knowledge and understanding was critical in determining their ability to pose questions, select tasks, evaluate their pupils' understandings and to make curriculum choices. Bennett and Carré (1991) support this view, saying that teachers need a sound subject knowledge and understanding in order to " frame accurate and high quality explanations, and they need it to diagnose accurately misconceptions".

Research into the influence of attitude on teacher effectiveness

Research into the influence of attitude on teacher confidence provides contrary evidence to the case for the importance of teacher subject knowledge and understanding as the most important factor in determining teacher effectiveness. Zuzovsky, Tamir and Chen (1989), for instance, looked at the difference in the attainment of fifth grade school students in Israel who were taught science by either specialised science or generalist science teachers. In Israel, pupils in the lower grades were taught all subjects by their homeroom teacher, but in the upper grades (4 - 6), specialised teachers taught specific subjects including science. Due to a shortage of specialist science teachers, the homeroom teachers sometimes taught science to the upper grades. This difference in pattern of staffing provided the context of the research. As Zuzovsky et al. point out, "it is commonly believed that specialist teachers (who only teach science) are better prepared, and are more familiar with professional literature and educational innovations in their area than are the general teachers (who teach most subjects, including science)" and "so consequently specialised teachers are expected to be more effective teachers". This supports the view that the "inferior scientific preparation of the general teachers accounts for the claimed low science achievement in the elementary school" (about half of the elementary school teachers were generalists). However, the researchers found that although the specialist teachers were judged to be better prepared and exhibited more adequate modes of science instruction, their pupils did not achieve any more than the pupils of the non-specialist teacher. This was because the generalist teachers had a more positive attitude to the study of science, which balanced out their poorer preparation and less adequate modes of science instruction. Thus, teacher attitude was found to be the important factor in determining teacher effectiveness.

Research into the influence of teaching style on teacher effectiveness

Teaching style also has an effect on teacher effectiveness, as several studies have shown. Effective teaching involves helping pupils to engage with and make sense of scientific ideas and concepts. McDiarmid et al. (1989), looking at secondary science, contend that teaching is about helping pupils develop "flexible understandings" of the subject matter, which they define as:

> The ability to draw relationships within the subject as well as across other disciplinary fields and to make connections to the world outside of school
>
> (p 193)

This view is supported by the findings of a mathematics education project, which shows that teachers who are able to make connections between different branches of mathematics, are more effective than teachers who are unable to make these connections are. In this project, Askew, Brown, Rhodes, Johnson and Wiliam (1997) carried out a study on what made an effective teacher of Numeracy for the Teacher Training Agency (TTA). They studied what 90 primary teachers knew, understood and were able to do in terms of numeracy, and the relationship between this and the outcome in terms of pupil learning. They found that the highly effective teachers had knowledge of and an awareness of conceptual connections between areas of the National Curriculum which they taught. The study found that, being a highly effective teacher of mathematics was not associated with having an 'A' level or degree in mathematics. This finding is in conflict with the findings of Whitby (1993) and Brown and Simon (1996) cited earlier.

Askew et al. (1997) found that some, but not all, of the less effective teachers of numeracy, displayed knowledge that was, "compartmentalised, and framed in terms of standard procedure, without the underpinning of conceptual links". This group included teachers who were highly qualified in mathematics. Effective teachers of numeracy were those who:

> …used pupils' descriptions of teacher methods and their reasoning to help establish and emphasise connections and address misconceptions.
>
> (Askew et al., 1997, p 1)

Thus it is the interaction of a teacher's knowledge and understanding with that of her pupils which is a crucial factor in the classroom, a point made by Golby et al. (1995). The ability of the teacher to highlight connections and address the pupils' misconceptions was not linked to the teacher's level of mathematics subject knowledge and understanding. Askew et al. developed a model of teaching that shows the relationship and interplay between the teacher's beliefs, knowledge and classroom practices. Teachers' practices are determined by their own subject knowledge and understanding, how they see the role of the teacher, their understanding of how pupils learn best, and most importantly, by the pupils' response. Askew et al. claim that it is "the interactions between teachers and pupils as they occur in lessons that will be the most significant influence that a teacher has on pupils' learning". Thus, according to Askew et al., however well prepared a teacher is and however well informed, what actually happens in the lesson is the crucial factor. They describe three types of teacher – 'connectionist', 'transmission' and 'discovery' – with regard to mathematics, (see Askew et al., 1997, p 31 for the summary table of comparison). Although no teacher fitted just one of these beliefs frameworks, they found that:

> Those teachers with a strongly connectionist orientation were more likely to have classes that made greater gains over the two terms (of the project), than those classes of teachers with strongly discovery or transmission orientations.
> (Askew et al., 1997, p 24)

This supports the view of McDiarmid (1989) cited above. Askew et al. found that the orientation of the teacher was not linked to their subject knowledge and understanding: i.e. having little subject knowledge and understanding did not mean that teachers were any more likely to have a particular teaching orientation. However, if a teacher believes that her/his role is to help pupils to accrue knowledge, then s/he is likely to place importance on her/his own subject knowledge and understanding: i.e. the more s/he has, the more s/he has to give.

The *connectionist* teacher emphasises the links between different aspects of the curriculum. A primary belief is that teaching is based on dialogue between the teacher and the pupils, so that the teacher can better understand the pupils' thinking and pupils can gain access to the teacher's subject knowledge and understanding.

The *transmission* teacher places more emphasis on teaching than on learning. Thus teaching is believed to be most effective when it consists of clear verbal explanations of routines, procedures and concepts. Interactions between teacher and pupils tend to be question and answer exchanges in order to check whether or not the pupils can reproduce the routine, procedure or concept being introduced to them.

The *discovery* teacher provides experiences for the pupils. The emphasis is on individual learning by the pupils: understanding is based on pupils working things out for themselves. Unlike the transmission teacher, the focus is on learning rather than teaching. The pace of learning is determined by the pupils.

The three teacher types listed above are not the only ones. The teacher as a 'co-learner' was found to be a popular idea with student teachers (Appleton, 1995). He acknowledged that teachers' lack of confidence to teach science was attributed to their poor background knowledge. Appleton asked student teachers about their confidence to teach science at the start and at the end of their course. Of the 55 per cent of students who completed the questionnaire, 71 per cent were more positive about science; 17 per cent were neutral and the rest negative. However, these students had a timetable problem, which could have accounted for their negative view. Appleton found that several student teachers felt that a small amount of knowledge was sufficient for the teacher, if the teachers viewed themselves as co-learners. The problem with this model is that if the teacher is learning alongside the pupils or is only a few steps ahead of them, how will he be able to select appropriate experiences for them and identify their misconceptions? As Appleton points out, "teachers with limited science knowledge may not be aware of pupil misconceptions and cannot offer alternative, helpful explanations".

Teachers can have the same teaching style – e.g. a 'traditional' style – but for different reasons, as the following two studies show. The first, by Lowden and Wallace (1994), compared the teaching style of two teachers, Malcolm and Susan. The second, by Tobin et al. (1990), looked at Peter, who like Malcolm adopted a 'traditional' teaching style, but for different reasons.

Malcolm took part in a School Board programme to increase the amount of interactive teaching in science. Susan, a teacher in Malcolm's school, also participated in the programme: both teachers were willing participants in the project. Malcolm favoured a more traditional approach to teaching. The children worked individually and there was an emphasis on basic skills in mathematics and English. Susan organised her classroom around active learning centres for most of the day. Malcolm and Susan were both considered experienced and successful teachers, although the headteacher was keen for Malcolm to alter his teaching methods. Indeed Malcolm himself felt the need to examine his own teaching and said that he was "in danger of becoming too conservative". Malcolm tried out a group work activity, but found that he spent most of his time on management issues rather than problems of science understanding. Malcolm was not committed to this new teaching approach, although he was willing to try it. He felt more confident maintaining his former practice. Lowden and Wallace, do not indicate why this new teaching style was considered better, nor do they say if there was more learning in Susan's classroom compared to Malcolm's.

Peter, like Malcolm, favoured a more traditional approach to teaching (Tobin et al., 1990), Peter's lack of confidence in his own knowledge of science meant that he relied heavily on worksheets and textbooks for material.

Although Malcolm and Peter appear to have similar teaching styles, the reasons for their chosen teaching styles are different. Malcolm was confident in his own science knowledge and understanding, but was afraid that a less traditional approach would result in poor pupil behaviour and thus undermine his authority as a teacher. Peter, on the other hand, was afraid that his lack of science knowledge and understanding would be exposed in a less traditional classroom and thus his authority as a teacher would be undermined. In both cases a change in teaching style with which the teacher was uncomfortable, would not necessarily result in more effective teaching and learning. As Malcolm said "I need to be an individual and keep my own integrity, do what I know is right". For Malcolm to change his teaching methods, he must believe that a change would enable him to teach more effectively.

Susan and Malcolm show that one teaching style is not always more effective than another. A traditional teaching style, as in Malcolm's classroom, can be effective. It is important to understand why a teacher has adopted a particular teaching style, as this might reveal some serious weakness. Peter might benefit from some professional development that would help enhance his science subject knowledge and understanding. Malcolm might benefit from professional development that would enable him to manage pupil behaviour more effectively.

In my research project I am attempting to identify the factors that determine a teachers' level of engagement with science. A teacher's teaching style can be a useful indicator of her/his level of confidence to manage pupil behaviour and to teach science, and of her/his own subject knowledge and understanding.

The types of knowledge that teachers need in order to teach effectively

Shulman (1987, cited in Harlen, 1999) provides a list of the different kinds of knowledge that a teacher needs in order to teach science. These are:

1. content knowledge - about science and of science;

2. general pedagogical knowledge - about classroom management and organisation that transcends subject matter;

3. curriculum knowledge - the guidelines, national requirements and materials available;

4. pedagogical content knowledge - about how to teach the subject matter, including useful illustrations, powerful analogies and examples;

5. knowledge of learners and their characteristics;

6. knowledge of educational contexts;

7. knowledge of educational goals, values and purposes, including the history and philosophy of education.

Content knowledge is placed first, as Shulman believes that several of the other areas of knowledge depend on it. Shulman does not argue that the teacher needs to know and understand every aspect of a subject in order to teach it successfully, but rather, that s/he needs:

> …an understanding of what identifies science; how the discipline differs from other.disciplines; what are its boundaries, its limitations and the different ways in which it can be conceived.
>
> (Shulman, 1991)

Grossman, Wilson and Shulman (1989), looking at secondary teachers, describe the different types of knowledge that a teacher must have;

1. Content knowledge - which they use to refer to "the stuff of a discipline: factual information, organising principles, central concepts";

2. Substantive knowledge - this includes the explanatory frameworks or paradigms that are used both to guide inquiry in the field and to make sense of data (Schwab, 1978);

3. Syntactic knowledge - this is knowledge of the "canons of evidence that are used by members of the disciplinary community to guide inquiry in the field. They are the means by which new knowledge is introduced and accepted into that community".

A teacher may have a high content knowledge, but know little of how the content of the subject has been constructed, and how to challenge it. Teachers who lack substantive knowledge and syntactic knowledge may be hampered by their ability to grasp new information in their field.

Primary teachers who do not know how science facts / theories are developed will not be able to guide their pupils' investigations effectively. Thus, syntactic knowledge may impact on pedagogy.

Morrison (1989) argues that kinds of knowledge other than subject knowledge are important for effective teaching: for example,

- knowing about children and how they learn,

- teaching strategy and

- communication.

Morrison supports the view of Calderhead and Miller (1985) who give an example of how a teacher uses different aspects of knowledge to teach about clouds. The teacher, they say, tailors his knowledge of the content to the context in which they are currently teaching, i.e. the teacher integrates his knowledge and understanding of clouds, with the pupils' needs and interests. This implies a grasp of the factors identified by Morrison which are listed above.

Findings from professional development in primary science

This section reports on the findings from professional development projects working with primary teachers. Most science educators would agree that teachers need some science knowledge and understanding. Given that many primary teachers cite their lack of science knowledge and understanding as an important factor in determining their confidence to teach primary science, the matter of science professional development for primary teachers must be addressed. Russell, Bell, McGuigan, Qualter, Quinn and Schilling (1992) contend that:

> "The argument that teachers should have a certain basic level of understanding of the science they teach is irrefutable" and that a "certain amount of science knowledge and understanding is necessary to teach the current curriculum is accepted.
>
> (pp 81-82)

However, they do not elaborate on what they mean by 'a *certain* basic level' or 'a *certain* amount of science knowledge and understanding'.

Russell et al. (1992) reported on the positive outcome of SPACE meetings for primary teachers. The Primary Science Processes and Concept Exploration (SPACE) Project began in 1986, that is, before the introduction of the National Curriculum. The orientation of the project was constructivist. The project concentrated on collaborative programmes of research into children's ideas in science and ways of helping the children to develop their understanding. The researchers worked closely with class teachers, meeting regularly to discuss concerns. They reported that "these meetings enabled teachers to begin to appreciate the possibilities of learning in science as an interactive rather than isolated activity and the group sessions appear to have contributed significantly to the development in teachers understanding". So, when given the opportunity to discuss their concerns and develop science understanding, the teachers made progress. Russell et al. (1992) quote some of these teachers:

> I can put my knowledge into a framework to use with the children at their level.

and

> Now I'll have a go, I feel a lot clearer in my mind where I'm going and why I'm doing things.
>
> (p 77)

Teachers mentioned that their confidence in their own science understanding had improved along with their teaching. This supports the findings of Carré and Carter (1991; 1993) who found that the teachers' feeling of competence with their existing knowledge and skills in science increased with teaching. Similar findings come from a study by Gooday, Payne and Wilson, (1993) involving first and fourth year B.Ed. students who were given a list of science items. For each item students were asked to rate their own understanding of it, their ability to explain it to children and its importance for children. The students were also asked about their confidence to teach science and their attitude towards science. The fourth year were found to be considerably more confident in teaching science compared to the first year students. They were more knowledgeable about classroom resources and how to use them and they also had a greater understanding of science processes. However, there was very little difference in the first and fourth year students' understanding of basic science concepts. The students had developed their general teaching skills through experience. In this study, teaching experience led to an increase in confidence. This might imply that a greater understanding of science subject matter is not important for a teacher's confidence to teach. However, an increase in confidence does not necessarily mean an increase in competence. A teacher might unknowingly teach confidently, but incompetently or ineffectively.

Harlen, Holroyd and Byrne (1995) surveyed 119 primary schools in Scotland: they used a questionnaire to find out teachers' confidence in their knowledge and teaching skills in different areas of the primary curriculum. They also wanted to find out how confident teachers felt that they had the knowledge needed to help develop pupil understanding of 26 'key features' of science and technology. The impetus for the research came from concerns about primary teachers own understanding of the concepts involved in teaching science and technology. This concern came from three sources:

- inspectors' reports;
- research into children's learning and its implications for the knowledge and understanding needed by teachers;
- research into teachers' perceptions of their own confidence and competence.

In all, 514 teachers responded to the questionnaire. The researchers found that having some science in their background – i.e. a previous science qualification – made the understanding of 'big ideas in science' by teachers more likely, but did not always guarantee it. The 'big ideas' came from both biological and physical sciences topics (Harlen et al., 1995). They also found that:

> The relative ease with which understanding of some 'big ideas' was developed by teachers suggested that there was latent understanding waiting to be awakened.
> (Harlen, 1999, p 76)

Although this did not apply to all of the ideas or all of the teachers who participated in the project, they found that it was:

> Sufficiently common to suggest that what holds back teachers' understanding is not ability to grasp ideas but the opportunity to discuss and develop them.
> (Harlen, 1999, p 77)

This has implications for teacher training programmes and INSET. Teachers may not need INSET to enhance their subject knowledge, but rather time to discuss and develop their ideas.

Conclusion

That primary teachers need science subject knowledge and understanding is clear. Of particular importance is knowledge of how different areas of science are constructed and how science areas and ideas are interconnected. Subject matter knowledge and understanding must, however, go hand in hand with a sound grasp of the other aspects of teacher knowledge: i.e. substantive and syntactic knowledge. Teachers must also know and understand how primary children learn. A university-educated physicist is not necessarily the best person to explain an echo to Key Stage One (5-7 year-old) pupils. The primary teacher, working with pupils who have little science to draw upon, must make connections with the pupils' experiences in school, at home and in both the real and imagined worlds. The effective primary teacher needs to know and understand the child's world in order to help make these connections. This does not necessarily result from having a high level of personal science knowledge and understanding (Khwaja, 2001). The effective teacher must also be able to select teaching methods appropriate for the pupils in his class. As Askew et al. (1997), reported:

> While a teacher may have a sound understanding of a mathematical idea, suitable teaching approaches need to be used in order to make the idea accessible to pupils.
>
> (p 20)

The literature explored in this paper shows that the picture of the factors affecting teacher effectiveness in primary science is a complex one, with many factors, other than teacher science subject knowledge and understanding emerging as significant. These other factors include teachers':

1. attitude to the subject;
2. ability to select appropriate and enjoyable experiences for the pupils, although this has been linked to the teacher's own subject knowledge and understanding;
3. ability to connect one area of subject learning with others;
4. view of his role as a teacher and hence teaching style;
5. interactions with pupils in the lesson, this includes identifying misconceptions, giving appropriate explanations.

The third point above does not necessarily imply more subject knowledge and understanding, but rather a different way of organising existing knowledge and understanding. Given the role of the other factors that contribute to the effective teaching of primary science, there is a need to "question the dominance of subject knowledge as a professional base for teaching", (Carré and Carter, 1990). The 1998 National Curriculum for Initial Teacher Education emphasised the following three areas:

- Pedagogical knowledge and understanding;
- Subject knowledge and understanding;
- Effective teaching and assessment methods.

However, many initial teacher educators found that Ofsted inspections focussed on the trainees' subject knowledge and understanding, although it was only one of three elements of the curriculum. Subject knowledge is one part of the 2002 standards for qualified teacher status which, unlike the 1998 curriculum, did not specify science subject knowledge. It will be interesting to see what emphasis Ofsted place on the trainees' subject knowledge, when the new inspection regime starts in September 2002.

Whilst most science educators would agree that subject knowledge and understanding is one factor in determining teacher effectiveness, that it is the most important factor, as we have seen, is debatable.

Mr M'Choakumchild had a secure subject knowledge and understanding, but clearly lacked those other areas of knowledge and skills, that might have made him feel more prepared to teach the pupils of Coketown.

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