Understanding Teacher Expertise in Primary Science
NEW DIRECTIONS IN MATHEMATICS AND SCIENCE EDUCATION
Volume 4

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Scope

Mathematics and science education are in a state of change. Received models of teaching, curriculum, and researching in the two fields are adopting and developing new ways of thinking about how people of all ages know, learn, and develop. The recent literature in both fields includes contributions focusing on issues and using theoretical frames that were unthinkable a decade ago. For example, we see an increase in the use of conceptual and methodological tools from anthropology and semiotics to understand how different forms of knowledge are interconnected, how students learn, how textbooks are written, etcetera. Science and mathematics educators also have turned to issues such as identity and emotion as salient to the way in which people of all ages display and develop knowledge and skills. And they use dialectical or phenomenological approaches to answer ever arising questions about learning and development in science and mathematics.

The purpose of this series is to encourage the publication of books that are close to the cutting edge of both fields. The series aims at becoming a leader in providing refreshing and bold new work—rather than out-of-date reproductions of past states of the art—shaping both fields more than reproducing them, thereby closing the traditional gap that exists between journal articles and books in terms of their salience about what is new. The series is intended not only to foster books concerned with knowing, learning, and teaching in school but also with doing and learning mathematics and science across the whole lifespan (e.g., science in kindergarten; mathematics at work); and it is to be a vehicle for publishing books that fall between the two domains—such as when scientists learn about graphs and graphing as part of their work.
Understanding Teacher Expertise in Primary Science
A Sociocultural Approach

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Understanding Teacher Expertise in Primary Science:
A Sociocultural Approach
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This book examines the very influential idea that science subject knowledge plays an essential role in the classroom practice of primary school teachers. In recent years, this idea has come to be seen, both by many researchers and by policymakers, as a major component of teacher expertise. Indeed, it is often argued that the effective teaching of primary science depends on teachers’ adequate understanding of scientific knowledge and of the ways in which this knowledge can be taught effectively to children.

Within research in primary science education, this emphasis on subject knowledge arose, to a large extent, from the growing influence of constructivist perspectives on learning and teaching. These perspectives are by no means homogenous, but they do share some important features in common. Above all, they emphasise the importance of establishing learners’ prior conceptions about the phenomena being studied and the need for teachers to challenge these conceptions directly during teaching. It is argued that, in order to be able to do this effectively, primary teachers must have sound science subject knowledge and an appropriate understanding of constructivist theories of learning and teaching. Since the 1990s, the definition of teacher expertise has been extended to include pedagogical content knowledge, which is seen as the kind of knowledge that “translates” what teachers know about science, children’s learning and teaching into effective pedagogy.

In order to explore these issues, in this book I will focus on two constructivist lines of thinking about expertise in primary science that have been influential within UK research. My aim is to examine the arguments and evidence on which they are based, and the assumptions they involve about knowledge, pedagogy, and learning; and to compare these with the rather different perspective provided by sociocultural theory.

This book is inspired by the belief that research on primary science education has not taken adequate account of sociocultural perspectives on knowing and learning, which treat these as necessarily situated and contingent. Above all, these perspectives stress that expertise is defined in action by relevant communities of practice: its character is tied to the perspectives and activities of those who are recognised as experts. This is not necessarily in conflict or incompatible with constructivism. However, it does provide a rather different view of expertise in primary science. Thus, the core of this book employs a sociocultural perspective to explore in-depth the perspectives and classroom practice of a teacher who is regarded locally, and to some extent more widely, as an expert primary science practitioner. The aim is to articulate what this can tell us about the nature of expertise in this field and its role in classroom practice.

In the current climate of government-led interventions around what primary teachers ought to know and how they ought to teach science, in the UK and also elsewhere, it is essential that we focus on how practitioners can enact their expertise in order to develop children’s scientific understanding.
ORGANISATION OF THE BOOK

The book is divided into two parts. The first is concerned with the assumptions about knowledge, learning and teaching that underpin the two constructivist lines of thinking about primary teacher science expertise that are currently influential in UK research. In the first chapter, changes in ideas about primary science are traced, and in particular the rise of emphasis on teachers’ subject knowledge, and on the importance of pedagogical content knowledge. In the following two chapters, constructivist views about primary science expertise are examined, in some detail, and compared with sociocultural views of knowledge and learning.

In Part B, I begin by discussing the implications of a sociocultural perspective for the methodological approach used to study teacher expertise in my own work (chapter 4), and then present a case study of a primary science teacher who was recognised as an expert practitioner. In chapter 5, I investigate the ways in which this teacher understands her own expertise. This involves an exploration of her views about scientific knowledge and its role in teaching, and her beliefs about the learning and teaching of science. Following this, in chapter 6, I provide a detailed analysis of an episode from her teaching, in order to describe the ways in which an expert practitioner enacts her expertise. This case study allows some assessment of the relationship between currently dominant views about primary science expertise and the form that such expertise can take in the classroom. In the conclusion, I summarise the argument as a whole, and examine the implications of my study for the education and professional development of primary teachers.
In this first chapter, I discuss the main reforms of primary science that took place during the past forty years in the UK, and how they lent support to increasing emphasis on the importance of subject knowledge for effective primary science teaching. I will argue that debates about the subject knowledge requirement have been influenced by changing views about the learner and the learning process, assumptions about the relationship between the nature of scientific activity and its products, and ideas about the value of teaching science in primary schools. I will also point out that, quite often, political factors have intervened to affect decisions about what and how to teach primary science.

The first section of this chapter deals with the curriculum reforms that took place in the 1960s. The second section describes some of the changes that occurred in ideas about the teaching of primary science during the 1970s. The third section focuses on the appearance of constructivism in science education and the introduction of the Science National Curriculum. And the last section describes the appearance of the distinction between subject knowledge and pedagogical content knowledge during the 1990s and current ideas about effective primary science teaching.

**PRIMARY SCIENCE IN THE 1960s**

It is often suggested that the beginning of the reform of UK primary science can be traced to the curriculum developments that took place during the 1960s. These developments re-activated discussions about the content and role of science in the curriculum, and how it should be taught.

At that time, science was not regarded as a core element of the primary school curriculum, which was still struggling to escape from the legacy of the *elementary* tradition, with its emphasis on the basic skills of literacy and numeracy and on the inculcation of pupil discipline (Richards, 1983). Where science was taught, it was treated simply as one more stimulus to children’s intellectual, emotional and physical development. For the most part, it involved the study of natural history, since encouraging children to explore aspects of the natural world built on their innate curiosity. Therefore, it could enable them to acquire an enduring love of nature and develop good observational skills, both of which were deemed necessary for the
subsequent stages of scientific learning. This reflected an inductivist conception of science which prevailed at the time (Hodson & Prophet, 1986).

An important contrast with the elementary tradition was the child-centred developmental (or progressive) tradition, which had begun to be mentioned in official reports on primary education from the 1930s onwards. The precise characteristics of this tradition are much debated (Blenkin & Kelly, 1981). In general though, influenced by the writings of Jean-Jacques Rousseau, Friedrich Froebel, Johann Pestalozzi, Maria Montessori and John Dewey, its supporters are usually identified as embracing “a broad set of educational values that are more centred on the child and the contribution of education to his or her continuing process of development, than on the child as someone being prepared to become some future “finished” educational “product” in fulfillment of society’s demands” (Hargreaves, 1986, p. 169).

Thus, typically, developmental educators de-emphasise subject divisions and focus on the process of knowing, rather than on its product. This is taken to mean that the central aim of teaching is to help children develop their ability to learn rather than to help them master a body of knowledge. Developmental educators see themselves less as specialists in a particular academic subject and more as gardeners (Claxton, 1990), responsible for providing the necessary conditions to enable growth to take place. They believe that children are intrinsically well motivated by direct, inquiry-oriented experiences and learn primarily through unstructured, play-like activities. They also favour a more co-operative relationship between teacher and children in the learning process, one which encourages children to play an active part in their own learning and development (see Blyth 1965).

The developmental tradition was closely associated with curriculum developments in primary science education in Britain in the 1960s. Thus, when, in 1961, the Ministry of Education expressed concern about the narrow content and poor quality of science teaching in primary schools, the emphasis was placed on finding ways in which improvement could be achieved whilst retaining the main principles of the developmental tradition.

The Appearance of the Process Approach to Primary Science

Some changes in the teaching of science had already been attempted in a few schools in the 1950s. Conran (1983), for example, argues that some primary teachers who were interested in science began to consider science teaching in terms of a series of practical investigations performed by the children themselves. Within this approach, observation remained the main skill that teachers were trying to promote, although teaching science also focused on developing children’s interests, attitudes and awareness of the natural world; on “exploring and appreciating (to some extent) patterns and relationships; on acquiring knowledge and developing the ability to communicate it” (p. 19). In some schools, the content of science was also broadened to include physical sciences in their curriculum. And, in order to overcome the problem of ill equipped classrooms, many teachers started to use everyday, commonplace materials in children’s investigations. Thus, children were encouraged to discover and explore the world around them and to ask questions, espe-
cially of the kind which could be answered by direct observation. However, among these teachers, there was little understanding of progression in children’s science learning, or of the contribution of science teaching to the child’s overall intellectual development.

In 1963, in order to support such initiatives in schools, the Science Masters’ Association (SMA) and the Association of Women Science Teachers (AWST), which now together form the Association for Science Education (ASE), established a committee to consider the nature of primary science. In its report, the committee argued that “we are concerned more with the developing of an enquiring attitude of mind, than with the learning of facts” (ASE, 1963, p.2). The ASE, before it established its primary science committee, had been concerned for some years about secondary school curricula and it developed the view that inquiry and experimentation should be a central feature of secondary science (Wastnedge, 1968). Around the same time, a similar view was expressed in the reform efforts of the National Science Foundation (NSF) in the United States. Taking into account the views of leading scientists, the NSF initiatives attempted to organise science curricula around the structure of scientific disciplines as modes of inquiry rather than bodies of knowledge, and laboratory work was seen as providing experiences designed to help students learn for themselves by operating as “scientists in the classroom” (Raizen, 1991, p. 18). This approach to learning about science by doing science became known as discovery learning. In Britain, “discovery learning” first appeared in the Nuffield Secondary Science projects (see for example, Nuffield Chemistry 1967), but soon influenced the primary projects, in which it became known as the “process approach” (see Wastendge, 1967).

The emphasis on discovery learning was further reinforced by the writings of Jean Piaget, especially his idea of the child as a lone discoverer, motivated to create and solve problems in an attempt to understand and organise the world around him/her (Hodson, 1996; Wood, 1988). Furthermore, Piaget’s descriptions of how such unstructured, self-directed observations and experimentation develop, through a series of stages, into sophisticated formal reasoning processes provided a guide to the issue of progression, and suggested a role for the primary teacher as the facilitator of the learning process.\(^1\)

Piaget’s ideas took some time to become widely known in Britain. His work was initially received with hesitation. During the 1950s, however, a number of books were published which interpreted Piaget’s theory for teachers, and some training colleges began to disseminate it, especially in the field of mathematics. Of particular importance in relation to the teaching of science was the work of Susan Isaacs, who reinterpreted Piaget’s ideas in the light of observations of children engaged in concrete problem-solving situations arising directly from their own interests (Harr len & Qualter, 2004). She noted that if children were treated as intelligent human beings, there would be very little in the way of learning and understanding that they could not master. Initially, though, this had little observable impact in schools.

Explicit support for Piaget’s theory was offered by the publication of the Plowden Report in 1967, which appealed to his theory in support of the argument that knowledge is best acquired through activity and experience.
In relation to science, this emphasis on action and doing blended well with the notion of science as a process of inquiry and exercised significant influence both in secondary and primary science curricula.

The Picture of Good Primary Science Teaching in the 1960s

It was against this background of general educational reform that the Nuffield Junior Science project (1964–1966) and the Science 5-13 project (1967–1975) were set up to help those teachers who wanted to use science as a means for educating children.

Based on Piaget’s theory about children’s natural drive to discover the world around them and on the view of science as a process of inquiry, the Nuffield Junior Science project (NJS) expressed the belief that children’s practical problem solving is “essentially a scientific way of working” (Goodwin & Wastnedge, 1995, p. 78). Therefore, the task of a school “is not one of teaching science to children, but rather of utilising the children’s own scientific way of working as a potent educational tool” (p. 78). In turn, the term scientific way of working (or how to think scientifically) was interpreted to mean the ability to isolate a problem, and, in working towards its solution, to be able to observe, investigate, communicate and most crucially to hypothesise and predict. Apart from the last two of these learning processes, which could be considered to be more characteristically scientific, the others were seen as general learning processes. For some authors, this approach to science learning blurred the distinction between science and other subjects and suggested an integrated approach to learning (e.g. Harlen, 1978).

According to the director of the NJS project (Wastnedge, 1967, 1968), science teaching should focus on helping children develop their abilities to ask their own scientific questions, isolate a scientific problem and find its solution through careful investigation. Furthermore, what is learned was seen to be inextricably linked with how it is learned. The project stressed that, given the increasing body of scientific knowledge, it was impossible to prescribe what one should know. Therefore, the only plausible criteria for selecting and organising scientific knowledge for the purposes of teaching can derive from children’s own questions, interests and needs:

We concluded, and believe very strongly, that a child should raise his/her own scientific problems, partly because isolating a problem is an important part of scientific thinking, partly because the ever increasing body of knowledge make it increasingly ridiculous to prescribe what any child should know, but mostly because we do not believe that anyone can ask a completely significant question for someone else.

This should not be interpreted as meaning that knowledge is not important. Obviously it is, but the content of what is learned should take its true place in relation to how it is learnt. (Wastnedge, 1968, p. 346)
Thus, the NJS project introduced a way of teaching science as a process of inquiry, and provided an answer to the problem of the narrow content of science by allowing children’s interests to decide what scientific knowledge they needed to know. The project seemed to value the application of science – that is, useful knowledge which can be established through practical investigation and applied to solve problems – more than abstract concepts and principles alone. To disseminate its findings, the project team set up in-service courses for teachers and produced books with background scientific information and topic-related activities, from which teachers could make their own programmes according to their children’s interests and abilities.

The project’s successor, *Science 5–13*, built on this work, but differed by providing teachers with explicit statements of the objectives for children’s learning. Thus, although the child’s motivation and the need for learning were still regarded as rooted in experience, the project included about 150 behavioural objectives which were grouped into three stages related to the Piagetian staged theory of intellectual development (Ennever & Harlen, 1972). These learning objectives aimed to guide the provision of opportunities for learning and to form a basis for monitoring individuals’ progress. Parker-Jelly (1983) argues that the project exerted significant influence on a range of policy statements and curriculum projects which were to emerge in the 1970s, such as *Match and Mismatch* (Harlen, Darwin, & Murphy, 1977), the *Sciencewise Series* (Parker & Ward, 1978) and the *Learning Through Science* project (Richards et al., 1980).

Thus, the picture of good primary science teaching that was predominant during the 1960s and 1970s was one which regarded science as a unique vehicle for children’s overall intellectual development, and scientific teaching as a process of inquiry through which learners acquire useful knowledge. Children should be encouraged to ask questions and find out answers for themselves until they are satisfied. To teach science successfully, primary teachers needed to have an understanding of how to recognise an appropriate scientific question, how to design experiments, evaluate evidence and draw valid conclusions; though they should also have adequate scientific knowledge on which to draw when guiding children’s investigations.

However, during this period other views also emerged about the teaching of primary science, which emphasised the teaching of abstract concepts of science. For example, in 1963, a project dealing with this was set up by the Ministry of Education. Based at the Oxford University Institute of Education, the project became known as the *Oxford Primary Science Project* (OPSP). Its main principle was that it is impossible to ignore that children will bring their own scientific experiences into school and, therefore, it is vital to include in the teaching of primary science the contribution of scientific knowledge in their interpretation of the environment (Redman, Brereton, & Boyers, 1968, 1969). Thus, the project took a diametrically opposite starting point from the Nuffield Junior Science project, which had been established in the same year, by prioritising four scientific concept groups, thought by a group of scientists to be the most important ones for young children’s scientific learning². The project considered how these concept groups
could be broken down into smaller units, by taking into account what was known about children’s intellectual development, and how these units could be understood by children through practical activities. It was thought that the child at the primary stage "may be able to make abstractions about the scientific experiences which he has, and to form scientific concepts in a simple, unsophisticated form" (p. 17). The project produced a book for teachers describing activities related to the four science concept groups. However, the project’s materials did not attract much attention at the time. For some authors, this is explained by the dominance of the child-centred approach to the teaching of the whole primary curriculum (Osborne & Simon, 1996a).

PRIMARY SCIENCE IN THE 1970s

Despite the curriculum developments of the 1960s and 70s, and the variety of curriculum materials produced for teachers to stimulate and support scientific activities with young children, the quality of science teaching did not seem to change dramatically (see Black, 1980; Boyle, 1990). It was suggested, that to a large extent secondary science teaching continued in its old mode of memorising facts, with little practical work, whereas primary schools continued to focus on nature study and training in observation. Kerr and Engel (1983), pointed out that although many primary teachers seemed to be aware of the existence of important curricular developments in primary science, and ranked highly objectives which could be achieved through planned scientific activity, there seemed to be little scientific activity carried out in primary classrooms. It was also suggested that some primary teachers who followed a “process approach” to the teaching of science engaged children in practical activities which focused exclusively on developing children’s understanding of processes, neglecting what was necessary to develop concepts more explicitly.

One of the reasons offered to explain the failure of these projects to be taken up by primary teachers related to the latter’s lack of confidence in teaching science, which in turn was associated with their poor science background and their failure to recognise the potential contribution of science to the curriculum. Whittaker (1980), for example, pointed out that primary teachers had neither sufficient understanding of the scientific process nor adequate knowledge of science to organise open-ended activities and to encourage the development of specific skills by carefully guiding their pupils’ own interests. She argued that teachers needed practical help to be able to use the ideas and the materials that exist. Furthermore, an HMI report (DES, 1978) argued that the major obstacle in the implementation of the curriculum materials was the lack of appropriate scientific knowledge among teachers. The report proposed steps to improve the situation which included the careful deployment of teachers who did have such expertise.

Thus, in order to improve the quality of primary science teaching, financial support was given during the 1980s for in-service courses, and Local Education Authorities (LEAs) were invited to apply for Education Support Grants for primary science. Part of the plans of those LEAs which received grants was to employ advi-
sory teachers to work in classrooms with other teachers (Harlen, 1995). Primary schools were also encouraged to develop policy statements for science and to create a post within their staffing of coordinator for science. These activities were intended to provide help to teachers in understanding and using the existing curriculum materials.

**Criticisms of the Process Approach**

However, during the 1970s criticisms had begun to emerge of the curriculum materials themselves. Some of these criticisms related to the absence of a common content for the science activities that young children were to be engaged in. Wynne Harlen (1978), for example, argued that although the idea of allowing children to select the content of the practical activities according to their interests is attractive, in practice teachers find it very difficult to follow the interests of a whole class of children. Even more importantly she pointed out, some children may not be interested in anything sufficiently to want to investigate, and therefore teachers may have to offer them specific problems. The absence of a common content could also mean that there would be repetition of experiences, especially when children moved schools, or that large gaps would appear in children’s scientific understanding.

It was argued by some that the main problem that the lack of common content indicated was that what science was taught was left to the choice of primary teachers, many of whom did not have the appropriate scientific understanding. As Kerr and Engel (1983), put it: “at present the content of primary science is left almost entirely to chance, a state of affairs which puts a considerable strain on conscientious teachers who lack sufficient background and experience of science” (p. 48). In turn, this argument is closely related to ideas about children’s learning in science. In her influential article *Does Content Matter in Primary Science*, Harlen (1978) argued that the choice of content should not be left to “chance, but should make sure that all children have the opportunity to gain basic ideas that lay a foundation for a gradually more sophisticated understanding of their world” (p. 618).

This shift in emphasis within discussions of primary science, from processes to content, is not unrelated to other changes that occurred during the 1970s and early 1980s. For example, in primary science education, attention was given, virtually for the first time, to the assessment of children’s performance. This led to consideration of children’s learning in science being not only in terms of their understanding of processes but also in terms of their understanding of concepts. More specifically, the *Assessment of Performance Unit* (APU), which was established in 1974 by the Department of Education and Science (DES), to “promote the development of methods of assessing and monitoring the achievement of children in school and to seek to identify the incidence of underachievement” (p. 9) developed a framework for assessment in primary science based on assumptions concerning the nature of the subject, its aims and objectives, and what children might be expected to be able to do as a result of their education. After consulting a number of interested bodies, such as the Association for Science Education, science was de-
defined as “an experimental subject concerned fundamentally with the solving of problems in scientific and everyday situations” (Gott & Murphy, 1987, p. 6). This view of science accepted the importance of processes, procedures and concepts of science in solving problems. From this perspective a framework for assessment was produced which included six categories. Five of these categories were process-based, whereas the sixth one involved the application of science concepts. In turn, thirty seven concepts were identified which were written in the form of general statements. The results of the APU surveys in the early 1980s indicated that the level of pupil performance was particularly low in relation to the more specific scientific skills (e.g. hypothesising and predicting) and in the application to scientific ideas. This focused future efforts to improve science teaching on these areas.

Furthermore, the 1970s found education experiencing a change in climate away from the progressivism of the Plowden era. This change may have influenced the re-emergence of discussions about the teaching of abstract concepts of science in the primary school. The latter could be seen as the consequence of a series of responses to the Plowden report, which began to make their appearance soon after its publication, challenging the assumptions of a child-centred education. In 1969, for instance, *Perspectives on Plowden* appeared, in which R. S. Peters argued that the general view of education taken in the Report was not appropriate to the practical needs of that time.

Around the same time several Black Papers were published (collections of critical articles predominantly from the political right) which, among other things, criticised child-centred education for failing to teach children discipline and respect for authority. In one of them, Bantock (1969) argued that Rousseau’s dichotomy between book learning and discovery learning is, at the very least, problematic, since it is possible to discover a great deal from books. These criticisms were further reinforced in 1976 when, in a speech at Ruskin College, the then prime minister, James Callaghan, talked about the “unease felt by parents and teachers about the new informal methods of teaching” and gave voice to the idea of “a core curriculum of basic knowledge” (Darling, 1994, p. 100). He also insisted that the views of politicians, parents and others should be taken into account and that educational debate could not be left exclusively to professional teachers. More support for the criticisms was provided by the publicity given to the failings of an individual primary school (William Tyndale School), which used what was labelled as a progressive approach to teaching. Around the same time a research report was published and widely reported, which claimed that children in “formal” classrooms made progress in English, reading and maths which was significantly superior to those taught “informally.” The report included the findings of an empirical study on how far primary school children progressed over the period of a year in different classes where the teaching style was classified as “formal” “informal”, or “mixed” (Bennett, 1976). Demands were expressed, especially by the press, to find out what had gone wrong in primary schools.

Harlen (1995) argues that such criticisms created a more sympathetic climate for the monitoring of standards, and made reception of work of the Assessment of Performance Unit (APU) easier. Also, the criticisms that undermined the intellectual
credibility of child-centred education led some authors to question whether the “process approach” was the most appropriate way to teach primary science (e.g. Driver, 1975). Such authors put forward arguments for adjusting the policy about content in primary science and for moving away from the “process approach” towards a view of teaching which pays attention to how children acquire both an understanding of processes and an understanding of content. Their arguments were associated with debates about the role of science in the curriculum, and with the emergence of a new interpretation of Piagetian theory about children’s learning in science, what became known as constructivism.

The Changing Picture of Good Primary Science Teaching

Throughout the late 1970s and early 1980s increasing concern was expressed about science and its role in the curriculum. Within the Association for Science Education, there was pressure to review the whole science curriculum (both primary and secondary) in order to establish an appropriate balance between the specialist and generalist aspects of science education. It had been argued that secondary science teachers continued to see the main purpose of science education as the supply of future scientists, with the result that two very different kinds of school science existed: academic science and non-academic science (Young, 1976). The curriculum developments of the 1960s and 1970s, especially the Secondary Nuffield projects, were said to have contributed to this division, by being essentially elitist and producing course materials intended for the minority of students who could cope with heavy conceptual demands (Boyle, 1990). These two kinds of school science were considered to be mutually exclusive; O-level and A-level courses had become increasingly abstract, whereas courses dealing with the everyday applications of scientific concepts were reserved for those not entered for examination. The likely consequence of this dual policy towards science education, it was suggested, was the emergence of two kinds of citizens: the scientifically literate and the scientifically illiterate. Thus, it was argued that there was a need for reform to produce a broad and balanced curriculum, which would offer to all pupils equal access to scientific literacy.

This argument for reform seems to reflect the principles that dominated the reform of science education in the United States at that time. During the 1980s concern there had shifted to the needs of academically disadvantaged students, and more broadly all those who were not destined for scientific and technical careers. Politicians and reform activists linked the quality of science education less to the excellence of the research establishment (central to the reform in the 1960s) than to the technical competence of the American workforce in the name of global competition. As Turner and Sullenger (1999) put it, in this atmosphere “science for all and scientific literacy became the watchwords of education reform, both in the United States and abroad” (p. 7).

Thus, by the end of 1970s, influenced by the argument of “science for all”, science in primary schools was officially recognised both to be important for the overall education of children, but also to be poorly practiced (see DES, 1978,
CHAPTER 1

1985). In this way, an approach to the teaching of primary science began to emerge which was trying to balance a process approach to learning with the acquisition of more abstract scientific ideas. Discussing the content of primary science, Harlen (1978) argued that what seemed to be required “are content guidelines that are firm enough to ensure that children encounter the range of ideas and facts which are relevant to understanding their environment, yet are loose enough to enable teachers to use a variety of routes to arrive at them” (p. 620). These content guidelines included statements such as: “all things are pulled down towards the earth; the amount of this pull is the weight of an object”, “some substances dissolve in water very well, others only a little and some not at all” (p. 622). Children were supposed to acquire such ideas through a variety of practical activities. This approach to the teaching of primary science was also embraced by the HM Inspectorate (see DES, 1978).

As I mentioned earlier, the search for an effective approach to the teaching of primary science which stresses the role of abstract scientific concepts was encouraged by the appearance of constructivism. This is discussed in the next section.

PRIMARY SCIENCE EDUCATION IN THE 1980s

In Britain, constructivism initially appeared in the context of secondary science education. By the end of the 1980s, it had established itself as the dominant approach to learning and teaching science among those writing about both primary and secondary education. Its assumptions about how children learn science, the nature of scientific activity, and what science teaching should involve, influenced decisions about the content of the Science National Curriculum (DES, 1989), and led to a reconsideration of the character of science teaching and consequently what teachers need to know in order to teach science effectively.

During the 1970s, research in secondary science education began to focus on the description and interpretation of students’ conceptions of various scientific phenomena. Until that time, most of the research into children’s ideas of science aimed to assess children’s conceptions against the accepted scientific ones. Students’ misconceptions were considered as an indication of some “defect” in teaching and learning. The re-discovery of the earlier work of Jean Piaget (1971), the arrival of post-positivist philosophies of science and the appearance of psychological perspectives such as those expressed in the work of David Ausubel (1968), Jerome Bruner (1966), Robert Gagné (1970), and George Kelly (1955), gave an impetus to the pursuit of a new research tradition in education, and in science education in particular (Gilbert & Watts, 1983). The term constructivism was used to label this emerging research tradition. It incorporated a wide range of theoretical perspectives, which appeared to share the assumption that the children being studied “must at a minimum be considered knowing beings”, and that “the knowledge they possess has important consequences for how behaviour and actions are interpreted” (Magoon, 1977, p. 652).

Thus, by the early 1980s there was a growing body of research into children’s ideas of a variety of science topics. Most of this research involved secondary
school pupils (e.g. Bell, 1981; Erickson, 1978), although there were also examples of research into the ideas held by younger children (e.g. Osborne & Freyberg, 1985). Such studies suggested that children bring to school their own interpretations of aspects of the physical world, which are often inimical to learning the ones held by the scientific community. Terms like alternative frameworks (Driver & Easley, 1978), conceptual frameworks (Driver & Erickson, 1983), and minitheories (Claxton, 1993) were used to label children’s intuitive ideas, and to indicate that these are different from those of school science. Consequently, some science educators began to suggest that there is a need to look more carefully, and in detail, at pupils’ own understandings and ways of thinking about scientific ideas, and to use this information in planning teaching strategies.

Of course, the notion that learning depends on the learner relating new experience to what he/she already knows was not new. It had been a central feature of many cognitive theories, and was an idea familiar to teachers. As Kerr and Engel (1983) put it, “good practice has always included listening carefully to individual children’s ideas and then beginning from the vantage point of the learner’s own experience” (p. 46). Constructivism, however, claimed to provide not only further evidence in support of the argument that new learning depends on previous learning, but also a better articulated theory of how children learn science and a better understanding of science as a human activity. Furthermore, constructivists argued that they were offering a “new pedagogy” for the effective teaching of science; one which aimed to “empower people to act more effectively in their daily lives” by enabling them to develop useful conceptual tools (Millar & Driver, 1987, p. 57).

More specifically, constructivist perspectives rejected the empiricist assumption that knowledge is passively built up from sensations generated by an observer-independent world. Instead, they presented knowledge in terms of “conceptual structures that epistemic agents, given the range of present experience within their tradition of thought and language, consider viable” (von Glasersfeld, 1989, p. 124). Accordingly, constructivist perspectives blurred the distinction between public forms of knowledge (knowledge as it is presented by scientists) and personal understanding (knowledge of the world as it is constructed by the individual), by suggesting that in both cases the construction of meaning is influenced by the personal beliefs and the values of the culture in which people live. Furthermore, by arguing that observations are theory-laden, constructivism also blurred the distinction between the processes and content of science. As Driver (1975) put it:

As theories have been discarded and others adopted, observations themselves have taken on a different significance. Observations are not absolute; what is observed is viewed through the spectacles which all those initiated into that branch of science wear. (p. 801)

Based on this view of knowledge, learning science came to be seen as an adaptive process of self-organisation through which individuals reconstruct their conceptual frameworks towards more viable or useful ones in order to carry out a task in a more effective way. As mentioned earlier, this view of learning science was based on a different interpretation of Piaget’s theory, one which stressed learners’ ability
to be active and reflective in the learning process. In particular, within Piagetian constructivism the learner was considered to be an intelligent adaptive problem-solver, who brings his/her conceptions to the learning process and constantly tests them against experience. Encountering a perturbation relative to some expected result, the learner may be actively induced to reconstruct his/her conceptions in order to re-establish a relative equilibrium between previous knowledge and the new experience (Driver, 1984).

From a Piagetian constructivist point of view, the teaching of science should aim to facilitate conceptual change by addressing the learner’s existing conceptions. In turn, practical activities, therefore, ought to be selected on the basis that they provide the necessary evidence which would force learners to confront the mismatch between their existing ideas and those accepted by the scientific community.

Thus, by arguing that “children’s ideas should be taken seriously”, Piagetian constructivism offered a new approach to the teaching of science, one which differed from didactic methods of teaching that failed to recognise the importance of children’s conceptions in the learning process. It also differed from the “process approach”, which assumed that children learn about science (learn the content of science) by doing science (getting involved in their own investigations) by arguing that children’s everyday ideas need to be elicited and challenged directly, so as to help them modify their initial understanding towards a desired scientific one. Driver (1975), for example, pointed out that if during the teaching of science children are left alone to choose their own questions to investigate, there is a danger that their enquiries will be set within the context of the science theory they already know, so that no conceptual change would be achieved. Furthermore, the “process approach” was also criticised for reflecting an inadequate understanding of the nature of scientific activity. It was argued, that there was no empirical evidence to support the existence of a clearly describable method of science. The commonly listed processes of science (observing, predicting, hypothesising, etc.) are aspects of children’s general cognitive functioning, and therefore science can lay no special claim to them (Millar, 1989).

On both sides of the Atlantic, during the 1980s and 1990s, many projects were set up to explore the nature and implications of learners’ prior knowledge of science. Some of these projects suggested particular teaching sequences to help children reconstruct their initial understanding. Such sequences usually involved an elicitation phase, during which the teacher would try to probe learners’ thoughts on the topic in hand and help them to clarify their ideas through engagement in individual work or group discussion (see Nussbaum & Novick, 1982). A second phase followed, in which the teacher should ensure that there is a direct contrast between the learners’ view and the desired scientific view. This could be achieved by presenting the “desired” view, or by somehow making it emerge from the class. During a third phase, the teacher should provide opportunities for the learners to see how the desired view is used in explaining a specific phenomenon and applying it to other examples. The teacher was seen as the facilitator of the process, responsi-
ble for creating the sort of environment necessary to help the learners to reconstruct their initial understanding (e.g. Driver & Oldham, 1986).

The Picture of Good Primary Science Teaching in the 1980s

Most of the studies mentioned in the previous section involved secondary school children and were aimed, primarily, at teaching secondary science more effectively. Soon, however, Piagetian constructivism appeared in primary science education as a theory which could provide a better explanation for how children learn. During the 1980s the aim of teaching science in the primary school was still to help children learn how to learn. Harlen and Osborne (1985), for example, argued that a rationale for primary science should start from a vision of the way in which we want children to learn and of the kind of learning we wish to promote, rather than in terms of teaching specific items of scientific knowledge. It has also been argued that constructivism in primary science facilitated the acceptance of defining the science content areas to which children should be introduced and suggested an interrelated view of the processes and content of science (Harlen, 1999).

In order to help teachers develop their understanding of a Piagetian constructivist approach to learning and teaching science, a project was set up in 1987, funded by the Nuffield Foundation. The project, which became known as Science Processes and Concept Exploration (SPACE), aimed to explore children’s conceptual understanding in science and the possibility of children modifying these ideas as the result of relevant experiences (SPACE, 1987—1990). The project carried out research in primary classrooms and its starting point was the ideas children bring to the learning process. Appropriate science activities were designed to enable children to test out their initial ideas and those of others against evidence, so that reconstruction of their initial understandings could be achieved. The project did not set clear objectives of what children should be expected to learn. Instead, it was suggested that the direction of development should be set out in broad terms to give guidance as to what it is sensible to expect of children at various points and that it should be possible to define the “big ideas” relating to both science content and procedures. In turn, these should be presented as aspects of development to which practical activities contribute. In the first phase of the project, from 1987 to 1989, eight concept areas were studied (Electricity; Evaporation and Condensation; Everyday Changes in Non-Living Materials; Forces and their Effect on Movement; Growth; Light; Living Things; Sensitivity to their Environment; Sound). The second phase of the project (1989—1990) included the study of a further ten concept areas (Earth; Earth in Space; Energy; Genetics and Evolution; Human influences on Earth; Processes of life; Seasonal Changes; Types and Uses of Materials; Variety of Life; and Weather). The research findings led to the development of classroom materials, known as Nuffield Primary Science (1993).

Thus, by the end of the 1980s, a new view of good primary science teaching was established, which emphasised the interrelated nature of content and processes and stressed the importance of children’s prior conceptions in shaping their learning process. Learning was seen as a process of conceptual change, which takes place as
children get engaged in practical activities, and are offered opportunities to reflect on and test their ideas against experiences designed to induce cognitive conflict. Good teaching requires the teacher to elicit children’s alternative ideas, plan progression for them and devise experiments which will challenge their conceptions and will help them to acquire the scientific view. And teachers’ knowledge of the theoretical constructs of science was seen as an essential prerequisite for effective constructivist teaching (see Harlen, 1999).

Piagetian constructivist perspectives provided a unified approach to the teaching of science for both primary and secondary education, and they influenced decisions about the Science National Curriculum, which was introduced for the first time in 1989. Its emergence and main principles, together with its implications for the teaching of primary science, are discussed next.

The Introduction of the Science National Curriculum

The 1980s ended with the introduction of the National Curriculum, consisting of ten “core” and “foundation” subjects plus religious education, and accompanied by a programme of attainment tests. Science was established as a “core” subject in the curriculum and had to be taught to every child in state schools in England and Wales (DES, 1989).

In general, the idea of a national curriculum was cautiously welcomed. Some saw it as an important means through which children are introduced to “valued skills, interests, attitudes, concepts and knowledge” (Richards, 1983, p. 3). However, within British society and its teaching profession, there was considerable disagreement over what is to be “valued”, and the content of the new national curriculum inevitably reflected that conflict. As Blyth (1978) had remarked many years earlier: “Everybody agrees that curriculum matters. This is probably the extent of agreement about curriculum” (p. 25). Such debates, together with accumulated criticisms of progressive approaches to education, made it easier for the involvement of politicians to appear necessary in sorting out educational matters. According to Darling (1994), the National Curriculum emerged within a climate which considered the freedom enjoyed by schools and local education authorities to determine the nature of the education provided for primary school children as a crucial weakness in a failing system. Moreover, the new, intensive programme of assessments tests, with school performances made public, introduced a system of “accountability” which put enormous pressure on schools and teachers. Nevertheless, the Science National Curriculum was conceived as an attempt to give all pupils throughout their compulsory education an exciting, broad and balanced experience of science (Jennings, 1992). It stressed the importance of continuity, progression and equal opportunities in primary and secondary science education; although it made clear the need for differentiation, to allow “the highest existing standards to be maintained for the most able” (DES, 1985, p. 13). The Science National Curriculum included clear objectives (attainment targets) for the knowledge and understanding, as well as the skills and aptitudes, which pupils of different abilities and maturity should be expected to have acquired at or near certain ages (DES,
Its first version (DES, 1989) consisted of seventeen attainment targets and multiple statements at ten levels for each one. Fifteen of these targets (AT2–AT16) dealt with knowledge and understanding, one attainment target (AT1) was concerned with the development of investigative skills, whereas the last one (AT17) dealt with the nature of science (this was not intended to be assessed at Key Stages 1 and 2). In addition to this, and in relation to the Government’s claim that regular testing would lead to the raising of standards, it was decided that pupils would be subject to formal testing at ages seven, eleven, fourteen, and sixteen. Furthermore, it was stressed that equal emphasis should be placed on content and process, both in teaching and testing.

However, the Science National Curriculum was soon found to be inconsistent with the assumptions which underlie a constructivist approach to learning. Harlen (1995), for example, argues that there was an “incompatibility between a curriculum structure which specifies objectives and the steps towards them and a view of learning which takes the learner’s ideas as the starting point” (p. 93). Furthermore, although science educators had seen the concern for conceptual understanding as intimately linked with the processes of investigation, the inclusion in the curriculum of processes and content in separate attainment targets was thought to discourage attention to their interrelationship (Black, 1993).

Primary teachers found the form of the Science National Curriculum unfamiliar, and even at odds with the science they were used to teaching. Their anxieties centred on interpreting curriculum statements and assessment, but the numerous ambiguities and inconsistencies within the different attainment targets of the Science National Curriculum, together with the lack of assessment requirement guidelines, did not make its understanding or implementation easy. On some occasions, teachers at both primary and secondary levels began to teach to attainment targets, believing mistakenly that these represented what was to be taught, rather than to work from programmes of study, which were designed to facilitate an investigative approach to learning (see Smith, 1994).

The prescription of content was one of the most significant features of the changed primary curriculum, and one result of this was that a lot of attention came to be placed on teachers’ ability to teach this content effectively. For example, in 1995, in the review of inspection findings conducted for the UK Office for Standards in Education (OfSTED, 1993/94), the inspectors argued that some primary teachers’ low level of subject knowledge, especially in relation to physical sciences, was detrimental to their teaching performance.

Since the beginning of the 1980s, some attempts to define an adequate level of subject knowledge had been made in policy documents concerning the training of primary school teachers (DES, 1983, 1985). In particular, these recommendations stated that at least two years A-level study of a subject related to the primary school curriculum should be an essential part of initial teacher training courses, and that one of the criteria for selection for postgraduate teaching training courses
should be a curriculum relevant degree (Calderhead & Miller, 1985). But, among science educators and researchers, such recommendations were seen as introducing a wide and intense programme of studies which could only encourage rote teaching and learning (Johnson, 1997). Instead, they suggested that teachers’ adequacy of subject knowledge should be defined in terms of their conceptual understanding: their ability to apply their understanding of the concepts including in the curriculum in giving explanations of relevant phenomena (Russell et al. 1992).

Nevertheless, during the 1990s the issue of the kind and amount of subject knowledge needed by primary teachers to teach science effectively became central in research on primary science education. Some studies suggested that many primary teachers lacked conceptual understanding of some of the main concepts of science, and that where teachers did have some understanding, their knowledge was not in accord with that of scientists (e.g. Kruger & Summers, 1989). Following on from this, many teaching materials were produced and professional development courses were launched in order to help teachers acquire the desired scientific understanding.

It is worth noting here that similar findings about primary teachers’ lack of science subject knowledge–particularly in the physical sciences, and confidence in their teaching of science were also reported in other English-speaking countries (Abel & Roth, 1992; Australian Foundation for Science, 1991).

Such studies increased the force of debates about the knowledge primary teachers need to possess in order to teach science effectively and the extent to which teachers’ subject knowledge influences effectiveness.

For some researchers, primary teachers are only capable of acquiring understanding of a small range of scientific concepts (Summers & Mant, 1995). Others argued that primary teachers are capable of acquiring understanding of a range of broad scientific principles (Harlen & Holroyd, 1995). These researchers also stress that in discussing teachers’ subject knowledge emphasis should be placed on teachers’ understanding of the nature of a particular scientific orientation.

With regard to the issue of the extent to which teachers’ science subject knowledge influences the effectiveness of teaching, different views were expressed. For example, while Harlen, Holroyd and Byrne (1995) argued that teachers’ poor subject knowledge seemed to affect their confidence and forced them to adopt various coping strategies, such as “teaching as little of the subject as the teacher can get away with it”, they also claimed that teachers’ knowledge about how to teach science may go “a long way to compensating for lack of scientific knowledge” (p. 99). Others placed more emphasis on teachers’ knowledge of scientific concepts as an essential condition for effective teaching (Osborne & Simon, 1996a, 1996b; Summers, 1994).

Research on Teacher Effectiveness

Further support for the subject knowledge requirement was provided by research on teacher effectiveness, which originated in the United States, in the mid-eighties. This kind of research shifted its focus from the identification of patterns of teacher
behaviour, which had been claimed to improve academic performance among pupils, to the study of the knowledge and beliefs which underlie effective teaching behaviour (e.g. Berliner, 1989; Buchmann, 1984). In Britain, until that time there was little research about the role of subject knowledge in teaching, although, there had been some studies on the professional socialisation of teachers (e.g. Lacey, 1977; Zeichner & Tabachnick, 1985).

Some of the research on teacher effectiveness was interested in teachers’ knowledge of the content being taught. Shulman’s work is one of the main examples of this type of research. He developed a model for conceptualising practice, which included a knowledge base for teaching and a pedagogical rationale for action; the “steps” that a teacher follows every time he/she teaches a subject (Wilson, Shulman & Richer, 1987, p. 106). Of importance, here, are his notions of content knowledge (or subject knowledge) and pedagogical content knowledge, which are at the core of the knowledge base for teaching; that is “the body of understanding, skills and dispositions that a teacher needs to perform effectively in a given teaching situation” (p. 106). Content knowledge refers to “the amount and organisation of knowledge per se in the mind of the teacher”, whereas pedagogical content knowledge is “the particular form of content knowledge that embodies the aspects of content most germane to its teachability” (Shulman, 1986, p. 9). Thus, within Shulman’s model, teachers’ understanding of subject knowledge is considered to be one of the most influential factors shaping teaching. As he puts it: “most teaching is initiated by some form of “text”, a textbook, a syllabus, or an actual piece of material the teacher or student wishes to have understood” (p. 14), and therefore, the teacher needs to comprehend the text before he/she decides how to teach it.

Shulman’s work soon became influential in research on science education, especially in the United States and Australia. Indeed, many projects focused on the identification of the main dimensions of teachers’ science pedagogical content knowledge with the aim of producing a model of teacher cognition which could be used for the purposes of teacher training (e.g. Gess-Newsom & Lederman, 1999).

The notion of science pedagogical content knowledge also shaped views about primary science expertise within UK research. More specifically, during the 1990s the group of researchers who carried out the bulk of research into teachers’ understanding of scientific concepts expressed concerns about primary teachers’ knowledge of constructivist pedagogy. It was argued, for example, that primary teachers still follow the process approach in their teaching of science thereby restricting children from developing understanding of scientific concepts. In order to address these concerns, this group of researchers launched continuing professional development courses, which aimed to help practicing teachers to acquire curricular expertise or subject specific teaching knowledge in relation to specific scientific topics. It was claimed that these term embraced both content knowledge and pedagogical content knowledge, thereby identifying the subject knowledge and specific pedagogical skills a teacher should possess in order to be able to help children acquire scientific understanding of a topic (Summers, Kruger & Mant, 1997a, 1997b). These researchers also supported a version of constructivist teaching, which stressed that in order to induce conceptual change, it is important that chil-
Children are introduced to abstract scientific concepts before their engagement in practical activities.

This view of the teaching of primary science is not unrelated to criticisms of the constructivist perspective that began to emerge during the late 1980s. Some of these criticisms related to the epistemological principles of constructivism, especially its antirealist stance and the implications of this stance for the teaching of science. Ogborn (1995), for example, argued that the abandonment of “realism as policy” has “led to a loss of nerve in science teaching, leading some to doubt the point and value of teaching science” (p. 3). Similarly, Matthews (1994) rejected constructivism for being subjectivist, empiricist, personalistic, and idealistic, and for tacitly assuming that “a child in isolation can discover and vindicate scientific truths” (p. 147). And Osborne (1996), drawing on Rom Harré’s realist philosophy, suggested that a realist conception of the subject matter of science need not lead to didacticism and can supplement constructivist pedagogy by making a place for telling, showing or demonstrating” (p. 74). Such criticisms usually claim that all that is beneficial in constructivist pedagogy, mainly the elicitation of children’s conceptions, can be preserved and used in other teaching approaches which could be more effective in helping children reconstruct their initial understanding.

Around the same time, Vygotskian views on learning appeared in the literature of science education research (see Koch, 2006). These views emphasised the role of language and communication in the development of children’s scientific understanding, and influenced changes in ideas about the nature of effective learning and teaching. In this way, within UK research on primary science education, a socio-constructivist version of learning and teaching emerged, which argued that children reconstruct their everyday ideas as they test these ideas and the ideas suggested to them by more knowledgeable others within children’s zone of proximal development (Driver et al. 1994; Harlen & Qualter, 2004).

Following on from this, in 1997, Harlen discussed pedagogical content knowledge as a broad framework that “enables” (p. 7) teachers to use their subject knowledge to support a socio-constructivist approach to the learning and teaching of science designed to help children acquire understanding of broad scientific principles.

These debates took place during a time when the British Government was expressing the view that teacher training should be conducted, as much as possible, in schools on an apprenticeship basis; a proposal that is based on the idea that teaching is a practical accomplishment that involves acquiring a battery of techniques to be deployed in the delivery of a pre-specified curriculum (see Alexander, Rose, & Woodhead, 1992).

Further support for this approach to teacher education was given by the introduction of the Initial Teacher Training Curriculum (DfEE, 1998), which detailed the scientific understanding and pedagogical skills required of beginner teachers.

Similar documents were prepared in many countries during the 1990s (e.g. the U.S. National Science Education Standards, 1996). Such standards-driven documents raised additional issues about the level of knowledge and pedagogical strate-
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gies that beginner teachers ought to possess and how this should be assessed (Nichols & Koballa, 2006).

PRIMARY SCIENCE BEYOND 2000

The beginning of the twenty-first century has been characterised by a worldwide trend towards standards-based education (see Appleton, 2006). In UK, this has been accompanied by further development in testing regimes, especially in relation to the assessment of student teachers’ understanding of subject knowledge. Many science teacher educators, for example, now use multiple-choice tests to assess student teachers’ science knowledge (such as that produced by the University of Cambridge Local Examinations Syndicate). At the same time, it has been suggested that, although primary teachers’ science knowledge is better than previously, they still lack understanding of the purpose of practical work in science learning, and confidence in engaging children in scientific investigations (Millar & Osborne, 1998).

Among UK primary science researchers, debates continue around the kind and amount of teachers’ science subject knowledge, as well as about the kind of pedagogical content knowledge, that is necessary. Indeed, currently, it is possible to identify two constructivist lines of thinking about teacher expertise. For one group of researchers, those whom I will call “small range” constructivists, the education of primary teachers should include their learning of a small range of scientific concepts and pedagogical skills. This knowledge should help primary teachers to introduce children to abstract scientific ideas prior to their engagement in practical activities. On the other hand, a second group of researchers, those whom I will call “big ideas” constructivists argue that primary science expertise requires their understanding of a broad range of scientific principles, as well as knowledge of the components of a particular scientific orientation. In turn, for these constructivists this knowledge is essential in helping teachers to use a socio-constructivist approach to the learning and teaching of science, through which children construct understanding of abstract scientific principles.

More recently, questions about the character of teachers’ science subject knowledge have been linked with broader discussions about the nature of scientific literacy. Some commentators have stressed the interdisciplinary nature of primary teaching, and have examined the place of science within an interdisciplinary school curriculum (see Roth, Tobin, & Ritchie, 2001). Others have argued that science learning should move beyond teaching children about the main concepts of science to include cognitive abilities that will enable them to use scientific knowledge in evaluating the effects of human activity to the natural world (e.g. Hodson, 1998; National Research Council, 1996).

Moreover, sociocultural interpretations of Vygotsky’s theory have appeared in science education research. These are framed by the assumption that knowledge and learning are necessarily situated within the activities of a science classroom community. As a result, they raise new questions about the nature of teachers’ sub-
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ject knowledge and their pedagogical. Nevertheless, their influence on primary science education research remains limited.

CONCLUSION

I have focused my discussion in this chapter on the main reforms of primary science that took place in UK during the past forty years, and how these lent support to an increasing emphasis on the importance of subject knowledge for primary science expertise. I began by describing the curriculum developments that took place during the 1960s, which were influenced by the child-centred tradition and aspects of Piaget’s stage theory. The picture of “good” primary science teaching that became predominant during the 1960s and 1970s was one which portrayed science teaching as a process of inquiry through which learners acquire useful knowledge. To teach science effectively, primary teachers needed to have an understanding of the process of inquiry and sufficient scientific knowledge to be able to guide children’s inquiries.

However, during the 1980s, “good” primary science teaching came to be redefined, as a result of dissatisfaction with the “process approach”, criticisms of child-centred education, discussions about the need for a broad and balanced science curriculum, and the appearance of Piagetian constructivist theories of learning. The emergent picture of “good” primary science teaching was one which maintained the principle that science teaching should aim to contribute to the overall intellectual development of the child, but it assumed that the content and process of science were interrelated, and that children bring prior conceptions to learning that need to be challenged directly during teaching. Furthermore, increased importance was given to the acquisition of abstract concepts as an outcome of learning.

Within this picture of science teaching, particular emphasis came to be placed on teachers’ understanding of the theoretical constructs of science, since this was seen as an essential prerequisite for effective constructivist teaching. This stress on subject knowledge was further reinforced by the introduction of the Science National Curriculum, the appearance of prescribed content knowledge which primary teachers had to teach, and the introduction of tests designed to assess children’s learning of this knowledge. As a result, during the nineties, the subject knowledge requirement became a major component of considerations of teacher effectiveness.

Around the same time, the distinction between subject knowledge and pedagogical content knowledge came to be made in the literature dealing with primary science education research. Furthermore, researchers saw the need to adjust their picture of “good” primary science teaching. From the point of view of “small range” constructivists, teaching should include introducing children to a limited range of abstract scientific concepts prior to their engagement in practical activities. For “big ideas” constructivists, teaching should engage children in activities where they are offered opportunities to test their own hypotheses and those of more knowledgeable others against scientific evidence.

So, at the beginning of the twenty-first century, debates about teacher expertise continue to focus around the kind of subject knowledge and pedagogical content
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knowledge that are necessary to ensure the effective teaching of primary science. However, these discussions take place in a climate where, on the one hand, there is increased criticism of Piagetian constructivism and a growth in influence of socio-constructivist and sociocultural perspectives, while on the other hand, from the direction of policy, there is an increasingly standards-driven view of teacher education.

NOTES

1 Hodson (1996) argues that in the United States the major impetus to discovery learning came from the writings of Jerome Bruner (1966) and Joseph Schwab (1962). In his influential essay "The teaching of science as enquiry" Schwab emphasises scientific inquiry as both content and method, and argues that laboratory experience should precede classroom teaching, and that the laboratory manual should 'cease to be a volume which tells the student what to do and what to expect' and be 'replaced by permissive and open materials which point to areas in which problems can be found' (Schwab, 1962, p. 55).

2 These concept groups were Energy, Structure, Change and Life.

3 Some work on assessment had been carried out on the Progress in Learning Science project (1973-1977, see Parker-Jelly, 1983).

4 It should be mentioned here that in the history of primary science, this is not the first time that discussions about the balance between teaching science for its utility and teaching science for its abstract concepts has taken place. Layton (1973), for example, argues that in the reform of elementary education that took place in the mid-nineteenth century a similar debate- between the teaching of 'science of common things' and the teaching of 'pure science' -- led to the exclusion of science from the elementary curriculum and the reduction of its content to the study of natural history, with an emphasis on observation.

5 Since 1989, there have been four revisions of the Science National Curriculum (1991; 1995; 1998; 2000), which reduced the number of Attainment targets to four.

6 This is defined as 'the distance between the actual development level determined by independent problem-solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers' (Vygotsky, 1978, p. 86).

7 A revised version of the UK Initial Teacher Training Curriculum, was produced in 2001 (Teacher Training Agency, 2001). A new revised version of this curriculum will be implemented in initial teacher education courses in 2007.
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THE SUBJECT KNOWLEDGE REQUIREMENT

In discussing teachers' science subject knowledge what is often implied is that, in order to be effective, a primary teacher must have a level of subject knowledge above some specified threshold. This has been suggested by Harlen (2000), for example, who argues that teachers need to have a “foundation for building a framework for teaching science” (p. 7). However, among researchers in primary science education in UK there are different views about what this foundation should consist of, which are shaped by different interpretations of constructivism. Thus, for “small range” constructivists, the foundation of teachers’ knowledge should consist of teachers’ adequate conceptual understanding of a small range of science concepts included in the English Primary Science National Curriculum. By contrast, for “big ideas” constructivists this foundation should take the form of adequate conceptual understanding of broad scientific principles along with understanding of the nature of a proper scientific orientation.

In this chapter, I discuss in detail the assumptions about the nature of knowledge and how it develops that underpin these two constructivist views and the methods used to determine teachers’ adequacy of subject knowledge. In the course of this, I will draw on a sociocultural perspective of knowledge and learning. This perspective stresses the complex interdependence of knowledge and action, and argues that knowledge and understanding are necessarily situated in the specific activities of communities of practice.

“SMALL RANGE” CONSTRUCTIVISM

“Small range” constructivists argue there is a substantial lack of conceptual understanding among primary science teachers about many areas of the primary Science National Curriculum, and that a considerable number of them experience great difficulty in acquiring the necessary scientific understanding.

On this basis, they argue that it may be unrealistic to expect that primary teachers, especially the ones with no science qualifications, to acquire adequate knowledge of all the concept areas included in the primary Science National Curriculum. Osborne and Simon (1996b), for example, claim that the science knowledge that primary teachers need to possess in order to teach science effectively to children can only be determined by a careful consideration of what science concepts most primary teachers are able to acquire adequately. Without such knowledge primary teachers are considered to be unable to identify correctly children’s
prior understanding or to plan their teaching so as to help children acquire the scientific view.

And so such authors concentrate their efforts on defining a more limited range of significant science concepts that primary teachers are capable of understanding. Summers and Mant (1998), for example, discuss the aspects of the concept of energy that should be included in the Science National Curriculum, arguing that these aspects should replace those aspects of balanced and unbalanced forces that teachers find difficult to understand.

“Small range” constructivists give little emphasis to the development of teachers’ problem-solving procedural understanding: their knowledge of the procedures needed to figure out what a scientific problem is about, and to collect and interpret evidence in order to address it. However, they are concerned with teachers’ acquisition of practical skills, such as how to wire a circuit. Indeed, they often imply that the development of problem-procedural knowledge should follow the acquisition of simple concepts and process skills. Moreover, they suggest that scientific concepts can be broken down into smaller parts and taught to teachers separately. These researchers, for instance, have identified, in order of difficulty, seven “simple concepts” (p.13) associated with aspects of electricity, which were easily understood by most primary teachers who participated in an in-service course on the topic. This points to a sequential view of knowledge acquisition on the part of these constructivists: the idea that simple concepts, facts and process skills (lower functions of cognition) are basic in individuals’ knowledge, and they exist as prerequisites to learning more complex or higher-order functions of cognition, such as complex concepts and problem-solving procedural knowledge (see Greeno, Pearson, & Schoenfeld, 1999).

It is important to note here that the sequential view of knowledge acquisition is part of a broader psychological approach, which is often referred to as cognitivism. Cognitivism was developed during the 1950s and 1960s in order to explain why students fail to or succeed in acquiring academic knowledge (see Murphy, 1999). It assumes that the mind and the environment are separate and have somehow to match one another. It uses computational methods and metaphors to model human learning and understanding, and is based on the assumption that there are certain universal features of human cognition (e.g. cognitive structures, short-term memory) that explain human thinking in general. Moreover, it assumes that human thinking involves logical deduction using context-free rules. In particular, within this approach knowledge is seen as a property of the individual mind, acquired during the course of solving problems thrown up by the environment. During this process, encoded symbols from the environment are stored in the individual’s memory in hierarchical structures that stand in one-to-one correspondence with the problem in the world. Each time an individual has to solve a new problem, he/she compares the information received from the environment with existing structures in the brain in a search of correspondence or difference. Thus, for cognitivism, a problem in the external world is represented inside the individual’s head and is solved using specific rules. From this point of view, learning and understanding depend on changing knowledge representations, and acquiring or strengthening
expert rules that would solve a given problem more efficiently (Bredo, 1997). From a sequential perspective, learners are expected to learn, first of all, the properties of the concepts of a discipline, and then the procedures by which such concepts are used to solve paradigmatic problems within the discipline. Such problems are clearly stated and have one correct answer, and concepts are treated as products or units of cognition which can be acquired in all-or-none integral steps (White, 1979). Understanding each of these steps implies that the individual possesses adequate description of its properties; and that, based on this description, he/she is able to correctly classify instances as examples or non-examples of the specific concept (Klausmeier, Ghatala, & Frayer, 1974). And, since it is the learner who is responsible for doing the problem solving in this model, cognitivism places particular emphasis on what an individual brings to a given problem. It suggests that the same data, such as a set of examples or non-examples of a concept, will have different impact on the conclusions drawn by various individuals or by the same individual at different points during his/her learning. Thus, in order to lead an individual to a certain conclusion, one needs to be aware of his or her prior academic knowledge and search strategy. The term misconceptions is often used to refer to individuals’ defective understanding of some of the properties of a specific concept.

Cognitivism is a feature of some constructivist perspectives, especially those influenced by Piaget’s approach, within which knowledge is “constructed in a slow process that begins with a simple sensory-motor schema during early childhood and progresses to complex schema without physical referents from the late teens onwards” (Roth, 1999, p. 6). Such perspectives place emphasis on learners’ everyday ideas, that is the ideas that individuals construct in their everyday interactions with the world. They argue, for example, that everyday knowledge can be an obstacle to the successful acquisition of academic knowledge (Gilbert & Osborne, 1980). From this point of view, in order to ensure the effective acquisition of academic knowledge attention is given not only to individuals’ prior academic understanding but also to their everyday understandings. Indeed, this is the approach to knowledge that underlies “small range” constructivism.

Acquiring Understanding of a Small Range of Science Concepts

For “small range” constructivists, teachers should be capable of constructing conceptual structures during their everyday interactions with aspects of the physical world. However, teachers’ understanding of scientific concepts is treated as sharply distinct from their everyday conceptualisations – the ideas that teachers construct in their everyday interactions with the physical world (Summers & Mant, 1995). Sometimes, this view of scientific concepts is associated with a modest realist perspective in which science is seen as involving a body of scientific propositions produced by the systematic testing of ideas against the real world. Each of these scientific propositions is treated as having a precise and fixed meaning that describes the universal properties present in all the phenomena being described. By contrast, everyday conceptualisations of a science concept (e.g. force) are seen as imprecise; they involve a variety of meanings or beliefs, which are specific to the
situations they describe. The term misconceptions is often used to describe such intuitive beliefs—ideas which are at odds with the currently accepted view of the science community.

At the core of this distinction between scientific and everyday knowledge is the belief that scientific knowledge is the product of a distinct form of reasoning about the physical world. Osborne (1996), for example, argues that the methods, procedures and criteria that scientists use to test hypotheses against the real world, to judge specific evidence for and against theory etc, are distinct from the ones used by other disciplines or by individuals in their attempts to understand their surroundings. On such a view, it is inappropriate to assume that teachers can acquire adequate understanding of scientific concepts through their everyday interactions with the physical world, though it is possible that some implicit understanding of a science concept may be obtained through such interactions. Summers et al. (1998), for instance, argue that some of the primary teachers who participated in an in-service course designed specifically to help teachers develop their scientific understanding of aspects of energy conservation, appeared to hold everyday ideas about the topic which were close to the scientific understanding of it. Thus, many teachers seemed able to explain energy conservation in terms of “saving” or using “less energy” (p. 311), though they appeared to be unaware that their everyday understanding was close to the scientific version of this concept.

In general, researchers who share this approach to judging the adequacy of teachers’ knowledge emphasise that scientific understanding can only be ensured if teachers are introduced to the correct definition of specific scientific concepts, so that they acquire an adequate description of the properties and relationships of each scientific concept and a clear understanding of the ways in which such properties and relationships are used to explain all instances of it. In turn, they argue that teachers’ introduction to scientific definitions should take place during in-service education courses and should precede teachers’ involvement with practical activities. In this way, teachers are expected to reconstruct their misconceptions and be able to use the predefined scientific explanation in explaining correctly relevant aspects of the physical world.

Of course, the process of acquiring an adequate understanding of a science concept is not smooth. It is possible that teachers may not acquire an understanding of all the relevant properties of a scientific concept, or that they may continue to use their misconceptions as well as their scientific understanding in explaining the same aspect of the physical world. Summers (1994), for example, commenting on the scientific understanding acquired by primary teachers who participated in in-service courses, says that “the scientific understanding achieved is likely to be partial and “messy” with, for example, misconceptions existing alongside scientific views and teachers unsure of their new knowledge” (p. 185).²

Thus, from this point of view teachers’ adequate conceptual knowledge of science refers to teachers’ possession of an adequate description of the universal properties and relationships of scientific concepts, and to their ability to use this knowledge in explaining correctly aspects of the physical world. Of course, primary teachers are not expected to acquire adequate descriptions of all scientific
THE SUBJECT KNOWLEDGE REQUIREMENT

concepts, or even of all of those included in the primary Science National Curriculum. This is judged simply not to be feasible. However, since for these researchers scientific concepts can be broken down into smaller parts, they argue that it is possible to identify the parts that primary teachers can easily understand and need.

Defining Teachers’ Adequate Understanding of a Small range of Science concepts

The methods employed to define teachers’ adequacy of science knowledge are usually semi-structured interviews and multiple-choice questionnaires. The interviews are carried out with a small sample of teachers to explore teachers’ views of the specific concept. The interviews often precede the use of questionnaires, which usually aim to establish the prevalence of misconceptions in a larger sample of teachers (see Kruger, Palacio, & Summers, 1990, 1992).

The type of interview often used in these studies is a variation on the Interview-About Instances (IAI) technique, which was developed in the late 1970s by Roger Osborne and John Gilbert to investigate students’ understanding of everyday words that are used in subtly different ways in science. The IAI method consists of dyadic discussions with participants, using a deck of cards as a focus. These cards contain line drawings depicting situations such as “a book lying on a table”, or real objects such as a “jumping toy car” (Summers & Kruger, 1990, 1992) and 3D models (e.g. Mant & Summers, 1995), which are used to prompt discussion about a particular aspect of a situation, such as the role of energy. The method rests on the choice of appropriate instances, so as to expose critical aspects of teachers’ knowledge. This is because, at the core of the design of the IAI technique, lies the assumption that understanding of science concepts is determined according to the individual’s ability to correctly classify instances as examples or non examples of a concept (Osborne & Gilbert, 1979, 1980). It is important to note that since the method rests on selection of an appropriate set of instances the researchers’ decisions about what the dimensions of an adequate description of a concept are, shape the findings.

The presentation of selected instances follows a particular order, which sometimes is the one that is described in the Science National Curriculum. During the interview, for each instance, the interviewer describes the situation and then asks the interviewee a focus question. Some of these questions require the teacher to decide whether a particular concept is contained in the specific instance. For other instances, the interviewer may explain to the teacher the meaning of the concept that is included in a specific instance (e.g. net force) before he/she presents the teacher with a number of different statements, from which the teacher is asked to decide which one describes the instance best (Summers & Kruger, 1993). On other occasions, the focus question aims to encourage the teacher to talk for a few minutes about a specific concept (Kruger & Summers, 1989). For each response, further questions are asked by the interviewer, aiming to clarify teachers’ meaning or probe further to elicit teachers’ understanding of the specific concept.

Quite often some of the instances used during the interviews are included in the questionnaire, together with a number of statements, from which the teachers are asked to choose whether they think the statement is true or false (and two more
choices are included: “don’t understand” and “not sure”). Sometimes, these statements are ideas that have been expressed by other teachers during interviews. Since the aim of such interviews and questionnaires is to identify teachers’ existing knowledge, particular emphasis is placed on not helping teachers with their responses (Summers et al., 1998).

The adequacy of teachers’ science knowledge is determined by the analysis of their responses to interviews and questionnaires. Thus, teachers who possess inadequate scientific knowledge are those who are unable to classify correctly the specific instances included in the interviews and questionnaires as examples or non examples of a specific science concept, or can only classify correctly a few of these. By contrast, teachers who classify correctly most of these instances are taken to have “complete” scientific understanding or, in other words, adequate subject knowledge. It is assumed that teachers’ ability to classify correctly a limited number of instances associated with a particular concept and to give reasons for their decisions in terms of a predefined explanation informs their ability to use the same concept correctly in the future. It is believed that, each time a teacher is faced with a situation which relates to an aspect of the physical world, he/she should be able to recall the correct scientific concept and classify this situation as an instance or a non instance of the specific scientific concept.

In evaluating this first type of constructivism, a key issue for consideration is whether adequacy of knowledge measured by interviews and questionnaires actually captures teachers’ practical science expertise.

**Questionable Assumptions About “Small Range” Constructivism**

As already noted, for “small range” constructivism teachers’ ability to explain experience correctly is a matter of matching the properties and relationships specified in a set of sentences with the properties and relationships present in the instances being described. There is a tacit belief here in representationalism, the idea that symbols mirror reality (Bredo, 1999). Yet a belief in representationalism could only be sustained if each scientific concept gathered together identical instances or at least very similar ones. Under such conditions, the application of such concepts would be unproblematic, and their involvement in science generalisations could make the application of other terms unproblematic. For example, the statement that a force is a pull or a push could be used to provide a precise and adequate explanation of all the instances associated with force, if it could be asserted that the instances associated with the terms pull or push are identical (the extension of the concept). In such a case, of course, the extension only needs to include one instance which could be the very idea of “force”, “pull” and “push”. This suggests an essentialist account of concept application. However, in practice, instances are not identical. For all the complexity of language, experience is much more complex and richer in information. Physical objects and events are never self-evidently identical with one another or possessed of a common essence (Barnes, 1974, 1982). Given this, teachers’ ability to make sense of experience is a much more complex matter than a cognitivist view of mind allows; it is fraught with ambiguity and un-
certainty. Responding to a situation involves exercising judgments about which concept is applicable in the particular situation, judgments that are often influenced by teachers’ perceptions and interpretations of the specifics of the situation and which cannot be easily codified or made entirely explicit (Bruner, 1966).

Following on from this, uncertainty or even failure in the task situation does not necessarily indicate lack of expertise on the part of teachers because understanding takes place over time and in context, rather than necessarily occurring at a fixed and predictable point. Indeed, some researchers argue that, given the dynamic nature of cognition, interviews “can only provide clues to ongoing cognitive processes” (Welzel & Roth, 1998, p. 40). Teachers may fail to respond adequately to interview and questionnaire demands, but reconstruct their understanding in a more scientific direction as they reflect on the problem later.

Finally, unlike the problems dealt with in interviews and questionnaires, those faced by teachers in classrooms may not be well-defined and therefore will need to be actively framed as problems before they are solved. Children’s questions and ideas about scientific concepts and phenomena may be expressed within contexts that are far more ambiguous and complex than the instances teachers are asked to respond to in constructivist research of this kind. Given this, in order for teachers to deal with such cases they may need to figure out the nature of the situation first, before they decide which concept is most appropriate to use (Bruner, 1986). Figuring out the situation may include framing and reframing the problem depicted in an instance, and trying out a number of different concepts to explain it, testing hypotheses, discussing the instance with children in the classroom or reading about specific concepts in resource textbooks. In doing this, teachers may need the problem-solving procedural knowledge of science to which “small range” constructivism gives little emphasis. Moreover, decisions about how to respond to situations that arise during teaching are often made on the spot, which heightens the need for contextual judgment and teachers’ reliance on their pedagogical expertise. However, the courses based on this approach do not introduce teachers to ways of thinking about ill-defined problems or pedagogical strategies for dealing with such problem-situations.

It can be suggested, therefore, that even if a range of science concepts can be defined that primary teachers are able to apply correctly in explaining a limited number of situations associated with them, this still leaves open the possibility that teachers may not be able to apply the same concepts successfully in all future situations. In other words, in some situations teachers may still express misconceptions about concepts which they previously appeared to understand adequately.

In summary, there are some serious questions to be raised about this way of approaching teachers’ adequacy of subject knowledge. Some of these concern the assumptions about the nature of knowledge, and about teachers’ development of scientific understanding. Others relate to the methods used to assess adequacy of teachers’ understanding. Above all, there are significant questions about the relationship between the understanding that teachers display in interviews and questionnaires and their practical expertise: their ability to use scientific knowledge in classroom situations.
CHAPTER 2

“BIG IDEAS” CONSTRUCTIVISM

A second group of researchers in UK primary science education, those which I called “big ideas” constructivists, argues that the foundation of subject knowledge that primary teachers need to possess in order to teach science effectively consists of conceptual understanding of a small number of broad scientific principles that are included in the primary Science National Curriculum, along with procedural understanding characteristic of a proper scientific orientation. Discussing the importance of teachers’ conceptual understanding of the “big ideas” of science, Harlen (1997) says:

Why “big ideas”? Because these are, in the end, what we want children to understand—not particular muscles in the arm, not the particular position of that image in the plain mirror, but the general ideas that help to explain muscle action wherever it happens and all the phenomena where images are formed. (p.7)

In turn, the necessary procedural understanding involves understanding that science begins with observation, and raising questions about what has been observed, and proceeds through predictions and hypothesising, planning and carrying out an investigation, collecting and interpreting data. Such understanding is associated with a view of science as a cooperative activity in which scientists use past and present ideas to produce knowledge that is conjectural, and is built up through the systematic testing of ideas against evidence (Harlen & Qualter, 2004).

“Big ideas” constructivists believe that the understanding of science develops as individuals interact with their own experience and with the ideas of others, and involves conceptual change. On such a view, procedural understanding is the means for acquiring conceptual understanding. In other words, knowledge of how to do science develops interactively with knowledge of concepts of science. Thus, this approach to teachers’ subject knowledge places emphasis on problem solving aspects of procedural knowledge, those which “small range” constructivists consider higher order and perhaps beyond the reach of primary teachers.

Another difference is that, while “small range” constructivists draw a sharp distinction between teachers’ everyday conceptualisations of physical phenomena and scientific concepts, “big ideas” constructivists argue that there are similarities between these; and that teachers’ misunderstandings can be seen as resulting from their making inappropriate links between experience and knowledge or from use of misleading everyday language. More specifically, drawing on a Piagetian constructivist perspective of the learner, “big ideas” constructivists argue that throughout their lives teachers construct conceptual structures as they test their ideas against experience (Harlen, Holroyd, & Byrne, 1995). These structures may involve ideas that are at odds with the accepted scientific ones. As a result, teachers’ everyday ideas may be linked to specific events as opposed to the “big ideas” of science that are used to explain a wide range of events. It is possible, though to foster and develop further teachers’ ability to test their ideas against evidence, to the point that it takes the form of scientific inquiry, thereby helping them to make appropriate links
between knowledge and experience. In other words, teachers need to be offered opportunities to develop procedural capability, so as to be able to test their existing knowledge against scientific evidence and use the evidence to make appropriate links between this knowledge and experience. Such reconstruction may also take place as teachers discuss their ideas with more knowledgeable adults, who may suggest different ideas for them to test. Indeed, influenced by Vygotsky’s work, this group of researchers emphasise the role of social interaction in the development of scientific understanding.

Following on from this, “big ideas” constructivists describe teachers’ knowledge of science as a network of links between scientific concepts and experience, which can be extended as teachers make new links between scientific concepts and ways of acting and interpreting evidence. Thus, developing teachers’ procedural understanding is seen as the key to educating primary science practitioners. This is not just because this understanding is fundamental for helping teachers acquire conceptual knowledge of the “big ideas” of science, but also because it is closely related to the ways in which teachers should help children develop their own scientific understanding in the classroom.

Nevertheless, teachers’ adequate conceptual understanding of the “big ideas” of science is regarded as central to effective teaching, since without it teachers’ are not in a good position to guide children’s scientific learning.

Defining Teachers’ Adequate Understanding of the “Big Ideas” of Science

Like the first type of constructivism, “big ideas” constructivists also use interviews to determine teachers’ adequacy of scientific understanding. The method used for determining teachers’ adequate knowledge of the Big Ideas of science is similar to the Interview-About-Instances method described earlier in this chapter. During such interviews, teachers are presented with events associated with specific scientific ideas. The means for presenting the chosen events to teachers are either coloured photographs, or simple equipment; and the related “big ideas” of science provide the framework for analysing teachers’ responses. For example, in order to explore teachers’ understanding of energy and electricity, they were presented with a battery-operated circuit which included a switch and a bulb (Harlen, 1996). This event was the focus of the interview which aimed to explore teachers’ understanding that current flow needs a circuit of suitable materials, switches make and break the circuit, and that the battery supplies electrical energy which is changed in the bulb to heat or light energy. Teachers were asked to discuss the particular event and to arrive at a collaborative explanation for the event, that is, an explanation that is satisfactory for both the teacher and the interviewer. During these interviews, the interviewer was checking constantly that what was suggested made sense to the teacher in terms of the evidence presented and other evidence that could be recalled.

Helping teachers in their explanations differentiates this approach from the previous one, in which teachers are not offered any kind of support in the interviews or questionnaires. For “big ideas” constructivists this kind of support is judged to
be appropriate because what is taken as teachers’ knowledge is not the knowledge that teachers appear already to possess but the understanding that they can achieve under the guidance of another more capable adult, and within the teachers’ zone of proximal development.

Thus, during discussions of a particular event, in some cases the teacher will provide the information and in other cases the interviewer will propose ideas to test out. In this way, the teacher not only develops his/her conceptual understanding but also his/her procedural understanding of science. Of course, not all of the “big ideas” included in the primary Science National Curriculum are easily understood by primary teachers. For example, ideas such as, current flow needs a circuit of suitable materials, and that switches make and break a circuit, are easily understood by most primary teachers. By contrast, the idea that the battery supplies electrical energy which is changed in the bulb to heat/light energy, is less easily understood. Nevertheless, it has also been suggested that given the opportunity, teachers can develop adequate understanding of many scientific concepts (Harlen, 1999).

Despite these important differences, this approach to teachers’ expertise, like the first one, treats knowledge from a cognitivist perspective. It seems to be assumed, for example, that once teachers have achieved a collaborative explanation for a particular event, they have acquired adequate knowledge for applying the concept in the future, both in the classroom and in other contexts. Indeed, doubts that might surround the interpretation of problem-solving situations seem only to be treated as acceptable during teachers’ acquisition of subject knowledge. These are not regarded as a significant part of teachers’ responses to situations that arise during teaching, at least not when they relate to a concept of which teachers have already been shown to possess adequate understanding. Instead, it is expected that such problem-solving situations are well defined, and that they can be resolved either by the retrieval of the correct big idea of science or by the application of a clearly defined scientific procedure.

What I am arguing, then, is that, despite their important differences, the two constructivist approaches to teachers’ subject knowledge I have discussed share some limitations in common, especially in terms of their interpretation of the relation between teachers’ knowledge and their classroom expertise. They assume a universalistic view of scientific knowledge: the idea that the concepts of science are abstract, precise entities which can be internalised into the mind of the individual teacher. Moreover, both approaches treat teachers’ understanding as taking the form of acquired, commodity-like knowledge that is essentially decontextualised and available to be applied across situations. From this point of view, once primary teachers have acquired the correct understanding of scientific concepts and/or of scientific procedures, they should be able to apply them in the future, both in classrooms and in other situations.

As mentioned in the beginning of this chapter, my questioning of these assumptions is based on some recent developments in the study of cognition. These emphasise that the construction of knowledge cannot be seen independently from the situation in which it occurs. A sociocultural approach to cognition offers a rather different picture of knowledge, understanding and learning, one which may have
important implications for how teachers’ adequacy of science knowledge is defined and for how it relates to classroom practice.

SOCIOCULTURAL APPROACHES TO KNOWLEDGE AND UNDERSTANDING

Unlike cognitivist approaches to mind, which treat the concepts and ideas expressed in language as representing the situations they describe - and therefore, as having an existence independent from the situation in which they were produced - sociocultural theories view the concepts and ideas expressed in language as the products of a particular line of societal activity which take their meaning from the context of that activity.

Like “big ideas” constructivists, they draw on Vygotsky’s work, but this time in treating language as providing the means or tools for social coordination and adaptation (Lave, 1993; Wertsch, 1985). Vygotsky’s work primarily contrasted practical ways of thinking associated with traditional society and the more theoretical and abstract ways of thinking introduced by modern educational institutions. Thus, it was directed toward modernisation and the learning of abstract scientific concepts.

Although it is difficult to generalise across this tradition as a whole, at this point, it is perhaps important to clarify the main theoretical insights which are endorsed by most psychologists of the Vygotsky school. In particular, Vygotsky’s theory is concerned with the social development of mind: the ways in which a person’s higher mental functions develop through social interaction (Axel, 1992). These higher mental functions – the mental capabilities such as thinking, believing, remembering, wishing, desiring, hoping, imagining, and so on – are embedded in or mediated by language. Language is an essentially social phenomenon, in the sense that it presupposes the existence of a set of shared social meanings (e.g. the theoretical propositions of physics) against which any communicative act has its reality. Such sets of shared social meanings are the products of a culture. Cultures are constituted by the socially significant forms of activity of a community: “historically evolved human attributes, abilities and modes of behaviour” (Leont’ev, 1983 cited in Davidov, 1988, p. 23).

Within Vygotsky’s theory, it is only through the appropriation of such socially significant forms of activity that the individual becomes capable of the higher mental functions. Activity, therefore, becomes the unit of analysis; it is the mediating agent between the individual and culture/society. In other words, higher mental functions must be understood as internalised forms of social activity. On such a view, appropriation is a process in which these social activities are translated from the social plane onto the individual plane, where they emerge in restructured form as the individual’s higher mental functions (Backhurst, 1988). This transformation of cultural to individual knowledge takes place in the zone of proximal development (ZPD). In this endeavour, linguistic expressions become the means by which individuals construct understanding of a situation and participate in the activities of a particular community. When there is problem in acting, the meaning of these expressions has to be negotiated and socially constructed. Thus, within Vygotsky’s
which is acceptable to the members of the particular community. Thus, for sociocultural theorists the activity becomes the unit of analysis rather than the individual’s mental structures.

Following on from this, sociocultural theorists emphasise the ambiguity and contingency of understanding. They argue that because knowledge as organised for a particular task can never be sufficiently detailed, sufficiently precise to anticipate exactly the conditions of action, the individual needs to be prepared to deal with contingency. As Keller and Keller (1993) put it:

An individual’s knowledge is simultaneously to be regarded as representational and emergent, prepatterned and aimed at coming to terms with actions and products that go beyond the already known. (p. 127)

Sociocultural perspectives direct our attention not to the individual who tries to build understanding independent of others, but instead to individuals as they are becoming functioning members of their communities before they become selves. It is important to note here that, unlike cognitivist theories which assume that novices’ ability to understand the expert depends on the possession of identical cognitive structures or representations of the task, within sociocultural perspectives novices’ ability to understand the expert depends on their ability to engage in and carry out successfully the activities of the relevant community (Roth, 1999). On this view, the “master” or expert is relatively more skilled than the novice in terms of having a broader understanding of the important features of a cultural activity. However, the expert’s depth and breadth of understanding is still developing in the process of carrying out the activity and in deciding which tools to use in order to guide others successfully in it (Rogoff, 1990). Following on from this, the essence of an individual’s understanding is its functionality: the ability to employ knowledge as a resource in order to achieve situated, contextualised goals emanating from problem-solving situations in the communities of practice to which they belong (see Greeno, Pearson, & Schoenfeld, 1999).

Sociocultural Approaches to Knowledge and Understanding of Science

Sociocultural approaches to the knowledge and understanding of science draw on a view of science as practice to argue that scientific culture is made up of all sorts of bits and pieces – material, social, and conceptual - that do not stand in any unitary relation to one another. The problems that scientists solve in the laboratory are frequently ill-structured; they may not provide all the information needed or they provide so much that the scientist has to make crucial decisions about which information to use as a basis for a solution. In such situations, scientists appear to use a variety of problem-solving approaches depending on the material, conceptual, and social resources available. On such a view, instruments, facts and interpretations of phenomena are collaboratively constructed, meanings and courses of action are negotiated, determined by consensus, or dictated by someone in power by bringing together the material, conceptual and social elements available in specific settings (e.g. Collins & Pinch, 1993; Latour & Woolgar, 1979). Following on from this,
sociocultural theorists view science as a form of *discourse*: “a social activity of making meanings with language and other symbolic systems in some particular situation or setting” (Lemke, 1995, p. 8). And they stress that the essence of doing science is the ability to examine the coherence of evidence and knowledge claims.

In turn, they describe the process by which novices become functioning members of a particular scientific community in terms of *enculturating* learners into the practices of a particular scientific community, so that novices learn, through *cognitive apprenticeship*, “the language, behaviours and other culturally determined patterns of communication of the scientific community” (Roth, 1993, p. 147). The metaphor of *enculturation* is associated with *situated practice* theory. This theory, while it is related to Vygotsky’s perspective, is quite distinctive because it considers cognition not solely as a property of individuals, but as being “stretched over” the individual, other persons as well as physical and symbolic tools (Sfard, 1998). Work on situated practice focuses on everyday ways of thinking and knowing: the ways in which individuals solve problems that arise in the performance of everyday activities of the *community of practice* to which they belong. In particular, it argues that problems found in everyday activities, such as those which arise when Liberian tailors learn to sew (Lave, 1988) or when grocery shoppers compare prices, are complex and often ill-structured; they may not provide all the information needed or they might provide too much. In such situations, individuals appear to use a variety of problem-solving approaches, depending on the specific situation (Scribner, 1985).

Furthermore, it has been suggested that problems which might be considered by outsiders as identical tasks were solved by means of different strategies. This indicates an inextricability of tasks from the setting. In other words, problems always change with the setting and become different problems altogether. Thus, within situated practice, learning and knowing lie in the relationship between the individual and the environment, where *environment* refers to both the physical, historical and cultural surroundings as well as to the problem solver’s ideas and beliefs relevant at the moment. And, since learning and knowing involve changes in activity in an environment co-constructed with others, they are considered to be *distributed* phenomena rather than residing solely in the heads of individuals (Roth, Tobin, & Ritchie, 2001).

An implication of a situated view of learning is that novices become functional members of a particular scientific community of practice as they observe and practice *in situ* the behaviour of members of this community. Brown, Collins and Duguid (1989), for instance, argue that following extended membership in the activities of a culture, novices pick up relevant jargon, imitate behaviour, and gradually start to act in accordance with its norms. Thus, learning a subject, such as physics, involves more than introducing learners to abstract concepts and self-contained examples. It involves exposing novices to the ways in which the members of a scientific community look at the world and how they use their conceptual and procedural tools to solve well and ill-defined problems. Initially, such exposure is expected to help learners develop a *tacit* understanding of what makes a relevant
scientific question or what is legitimate or illegitimate behaviour in a particular activity.

Novices become fully-fledged members of a specific scientific community as they participate in joint authentic activities with experts, during which, they learn, through a process of cognitive apprenticeship, how to conduct research from the beginning, through to the end of a research project (Roth, 1995, 1996). And, this involves learning about the tools of science, about how to identify a problem and how to proceed to its solution, by trying out different concepts, raising questions, testing a proposed idea, negotiating and discussing the proposed solution with other members of their community until a solution is sought which is acceptable by the other members of the community.

Moreover, learning the discourse of science involves learning how to argue over the efficacy of the warrants of science for knowledge claims. This is a difficult process because everyday language is often inconsistent with scientific discourse. Thus, an important part of learning science is to offer learners opportunities to express their everyday conceptions in order to learn how to “identify when and how their everyday discourse is compatible with the discourse of science and to figure out ways to resolve inconsistencies” (Tobin, & McRobbie, 1999, pp. 218—219). This process takes place within the context of a specific activity, and involves a process of negotiation and consensus building with the other members of the learners’ community of practice.

It is worth noting here that, sociocultural approaches to the learning of science have some similarities with the view of how scientists’ understand scientific concepts which was suggested by Thomas Kuhn (1970, 1977) and developed further by Barry Barnes (1982). According to this view, the concepts and laws of science are tools or conventional representations of the physical environment which are used to group, order and pattern the objects and processes encountered in nature according to their similarities and differences. Understanding of these conventions is acquired by carrying out paradigmatic procedures, which highlight the relations of similarities and differences currently accepted by the specific scientific community. From this point of view, paradigms, that is to say the problem-solutions that students and scientists encounter during their education or research career as exemplars of how the specific scientific community does its job, are the means by which new members of the scientific community acquire understanding of scientific generalizations. And, because instances of these generalisations are not all identical, this understanding is not static but dynamic: it develops each time a scientist uses a tool to solve a particular problem. Moreover, there are sometimes problems where nothing seems the natural concept to apply. And, this is because each time a scientist decides to use a tool in a new situation, he/she needs to assert resemblance between the new situation and a previous one. The idea of resemblance involves the individual’s judgment that similarity outweighs difference. And this judgment arises from the “the routine operation of the agent’s own perception and cognition – something which is contingent and revisable” (Barnes, 1982, p. 26). Like sociocultural theorists, for Kuhn and Barnes misconceptions are seen as part of learn-
ing how to do science rather than as a deficit in the acquisition of a correct description of the properties of a specific science concept.

*Sociocultural Implications for Teachers’ Adequacy of Subject Knowledge*

From a sociocultural perspective, teachers’ science subject knowledge consists of a rich, dynamic and evolving network of links between the ways in which a particular concept is used in a number of different situations and of the situations. This network would develop and change each time a teacher uses a particular concept to act successfully in a specific situation. Furthermore, teachers’ understanding of scientific discourse would be seen as emergent, with the aim being to come to terms with actions and products that go beyond the already known. And it would be described as an evolving spiral, in which simple concepts, facts and process skills and complex concepts, procedural knowledge, perception, remembering and feelings of uncertainty develop interdependently as teachers participate in socially and culturally organised activities.

It is important to note here that like constructivist perspectives, sociocultural theorists also emphasise the crucial role that knowledge plays in practice (see Edwards, 2005; Tobin, 1998). However, given that they recognise the essential and inseparable roles of cultural tools, social activity, and individual efforts, sociocultural theorists argue that the assessment of an individual’s knowledge should be based on how this person performs, and not on what this person says about his/her own performance or what he/she can and cannot do in artificial situations.

Some sociocultural theorists have used interviews and questionnaires to assess secondary students’ knowledge of aspects of physical science. Welzel and Roth (1998), for example, interviewed 13 grade 6-7 students at the end of a four-month classroom unit on simple machines. Prior to and at the end of the unit, students were tested in a number of ways which included their responses to paper-and-pencil questions about three real-life situations that illustrated applications of levers, pulleys and inclined planes. However, unlike constructivist interviewing, these interviews were designed to take into account the dynamic and situated nature of cognition by regulating the complexity of the tasks that were offered to the students, allowing students sufficient time for the development of situated cognition, and by explicitly participating in the cognitive activities of the interviewees. Indeed, the aim of such interviews was to assess the “maximum level of complexity that interviewees can enact at a specific moment in time” (p.40, emphasis mine).

However, more usually, a sociocultural perspective directs our attention to the study of teachers’ performances in the activities of their communities of practice in order to assess adequacy of subject knowledge. And, teachers can be seen as participating in a variety of communities of practice, such as those formed by staff in a particular school, those made up of teachers and mentors in initial teacher education and continuing professional development courses, and that constituted by the teacher interacting with children in a particular classroom. In turn, the nature of the problem situations that teachers deal with depends on their context, and different problems require different kinds of solution, which in turn require differential use.
of cultural tools. Indeed, sociocultural theorists emphasise that learning is a process of boundary crossing mediated by access to different communities of practice (Engeström, Engeström, & Karkhainen, 1995; Lave, 1993). Furthermore, they point out that developing expertise is a matter of social relationships and identities within different communities of practice, in which novices learn how to use tools of various kinds to solve the problems of the specific community (Lave & Wenger, 1991). And, they argue that, increasing access and participation, within and between different communities of practice, would increase “individual and collective knowledgeability” (Guile & Young, 1998, p. 114).

On this view, adequacy of subject knowledge is a complicated issue which involves assessing their use, and limitations on their use, of cultural tools, in relation to particular tasks, in particular contexts, and in particular moments in time. Thus, one way to determine adequacy of teachers’ subject knowledge is functionality: their ability to make decisions on which concepts are more appropriate to use and how these should be used in problem solving situations of different communities of practice, including situations that arise as they participate in their science classroom communities.

CONCLUSION

In examining the two main constructivist approaches to teachers’ science subject knowledge I have identified some differences between them. These relate to their assumptions about the relationship between conceptual and procedural knowledge and to their views of the role that social interaction plays in the construction of teachers’ scientific understanding. In turn, these differences have implications for determining what form teachers’ science subject knowledge should take.

For “small range” constructivists, teachers’ knowledge in science develops in a sequential manner: the concepts, facts and practical problem skills are basic in teachers’ knowledge, and exist as prerequisites to learning more complex or higher-order functions of cognition, such as complex concepts and problem-solving procedural knowledge. Following on from this, “small range” constructivists argue that teachers’ subject knowledge needs to consist of a limited range of simple science concepts and practical process skills, and these should be introduced to teachers during initial or continuing professional development courses.

By contrast, “big ideas” constructivists adopt a socio-constructivist perspective on knowledge. This argues that teachers can acquire adequate understanding of broad scientific principles through their testing of their prior conceptions and the ideas offered to them by more knowledgeable others against scientific evidence. In turn, teachers’ subject knowledge is treated as involving an expandable range of broad scientific principles and a particular approach to doing science. In line with this, it is argued that the education of teachers should offer them opportunities to develop adequate understanding of problem-solving, not just because it helps them to extend their own scientific understanding but also because it is central to children’s learning of science.
theory individual actions and mental representations are understandable as integral elements of the activity systems in which they function, take shape, and which they in turn constitute (Engeström, 1988). In other words, thought and speech are instruments for the planning and carrying out of tasks, just as eyes and hands are.

Influenced by Vygotsky’s theory, sociocultural approaches to cognition hold that “what we take as knowledge and how we think and express ideas are the products of the interaction of groups of people over time” (Putman & Borko, 2000, p. 5). Throughout their lives, individuals participate in various communities of practice, ranging from scholarly disciplines such as Science and History to groups of people sharing a common interest, including those operating in particular classrooms. Each of these communities, generates tools, a set of shared social meanings, which its members use to interpret and negotiate their interpretations with one another, thereby enabling them to continue to act successfully in the activities of that community. In the course of this process, people develop, often tacitly, rich networks of links between specific tools and situations, which are employed to make sense of future situations. And because situations are not fixed or identical, each time an individual uses a tool to construct understanding of a new situation that resembles an old one, he/she develops a better understanding of both the tool and the situation itself. As Brown, Collins and Duguid (1989) put it:

People who use tools actively rather than just acquire them build an increasingly rich implicit understanding of the world in which they use the tools and of the tools themselves. The understanding, both of the world and of the tool, continually changes as a result of their interaction. (p. 33)

An important implication of sociocultural approaches to knowledge is that an individual’s understanding of the concepts, theories and ideas of a particular community is a dynamic process resulting from acting in situations and negotiating with other members of the community. Furthermore, such understanding is constructed first on a social plane before it becomes internalised by the individual, and is best described as an “evolving spiral” (Patricia Murphy, personal communication), in which lower mental functions (e.g. concepts and facts, and simple process skills) and higher mental functions (problem-solving procedural knowledge, complex concepts, perception, remembering, etc.) develop interdependently as individuals participate in socially and culturally organised activities.

This is a very different approach from treating understanding as involving the application of a static set of concepts and procedures, as within cognitivist approaches to mind. For example, in their attempts to act successfully in an activity of a specific scientific community, individuals may initially perceive the task as unfamiliar and feel unable to understand it. On such occasions, the situation in which the blockage occurs forms the practical background for the thinking. Individuals may decide to examine the actual site of the problem, to look around, negotiate it with other members of the community, choose which tools could be used to make sense of it, to help determine the nature of the problem. Testing the proposed solution involves practical action to see whether anticipated consequences occur, that may lead to further thinking, testing and acting until a solution is reached.
Despite their differences, both approaches treat teachers’ understanding of scientific knowledge as acquired, commodity-like knowledge that is essentially decontextualised and available to be used across situations. This is evident in their approaches to the assessment of teachers’ adequacy of their science subject knowledge, which they define according to their ability to retrieve or collaboratively achieve the correct scientific knowledge and apply it in their explanations of well-defined situations that are included in interviews and/or questionnaires. From this point of view, both approaches to teacher expertise assume that once teachers acquire adequate understanding, of either a set of simple concepts or of a range of broad scientific principles, they are able to apply these in the classroom with the use of appropriate means. And in this way, they underestimate the complexity of practice.

These criticisms derive from sociocultural perspectives, which treat the concepts, theories and ideas of a scientific community as tools: the products of a particular line of inquiry which can only take on meaning in that context. Drawing on Vygotsky’s work, they stress that understanding of the scientific discourse is often messy and contingent and depends upon processes of interpretation and negotiation of the problem at hand. Thus, teachers’ science subject knowledge should be conceived as a dynamic process resulting from acting in situations and negotiating with other members of their communities. Moreover, its adequacy should be determined by functionality: by assessing teachers’ ability to employ tools skilfully in order to achieve specific goals.

NOTES

1 Conceptual understanding refers to the individual’s ability to explain aspects of the world by identifying correct links among ‘items’ of knowledge (see Hiebert & Lefevre, 1986).
2 It should be noted here, that researchers who share this approach to teachers’ adequacy of science knowledge use the term misconceptions to refer not only to teachers’ intuitive beliefs but also to teachers’ partial understanding of a science concept (see for example, Summers & Mant, 1998).
3 Examples of such principles are “water exists as solid, liquid and gas”, “switches make and break the circuit”, “the battery supplies electrical energy which is changed in the bulb to heat/light energy” (see Harlen, 1996, p. 6).