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Paying lip-service to research?

The adoption of a constructivist perspective to inform science teaching in the English curriculum context

Abstract:

Constructivism is a widely influential perspective in science education research. However, there have been strong criticisms of attempts to adopt constructivism as a principle underpinning official science curriculum policy (for example in New Zealand). Over the past decade recommendations for classroom pedagogy in extensive official guidance (particularly through the 'National Strategy') issued to science teachers working in England have explicitly drawn upon constructivist principles. Yet there has been little public debate about this aspect of the guidance or its reception by teachers, and there are reasons to expect that the potential impact of the recommendations has been severely compromised by the nature of the guidance, and the wider curriculum context. As recent substantive curriculum revisions rely upon science teachers adopting new pedagogy, research is indicated to explore how teachers construe and respond to pedagogic recommendations disseminated through official guidance.

Keywords:

constructivism; official pedagogy; curriculum guidance; English National Curriculum; National Strategy; learners' misconceptions

Paying lip-service to research?: The adoption of a constructivist perspective to inform science teaching in the English curriculum context

Introduction

This paper discusses the nature of one aspect of pedagogical advice that has been incorporated into a range of official documents advising English science teachers by the UK government and its agencies over the past decade and in particular the science strand of the Key Stage 3 (as was) National Strategy. This particular aspect of pedagogy is 'constructivism'. It is important to explore this issue because (a) constructivism has been widely recognised as the dominant viewpoint or paradigm informing science education *research* since the late 1970s; but (b) attempts to incorporate constructivist approaches to teaching science have drawn strong criticism in some quarters. Yet, in England, there seems to have been little open objection to the constructivist nature of official curriculum advice, and indeed little comment on the matter. Indeed the science strand of the National Strategy seems to have attracted limited academic attention, compared with some other strands, e.g. (Brown, Askew, Millett, & Rhodes, 2003; Wyse, 2003), perhaps reflecting the earlier relatively limited opposition of a prescribed curriculum by science teachers when compared to some of their school colleagues (Donnelly & Jenkins, 2001).

It is in this context that the nature of the pedagogic advice was analysed for the present study, to identify the 'flavour' of the constructivism that appears to have been granted official recognition by the English authorities. It will be argued here that the form of institutionalised constructivism inherent in English curriculum guidance may be seen as unobjectionable partly because it does not require radical changes in teachers' practice. However, this sanitised version of constructivism achieves this by avoiding some of the key messages deriving from research into student learning. It is suggested here that research is needed to find out precisely how the guidance is being understood and implemented in classrooms. This is considered especially important in view of current revisions of the science curriculum in England (QCA, 2007a, 2007b), which require science teachers to adopt new teaching approaches.

This paper therefore first explains the nature of constructivism in science education, and the criticism it has attracted, as background for an account of the constructivist content of guidance issued to support teaching science in England. The version of constructivism incorporated into curriculum guidance is explored, and the question of the minimal comment or resistance form the profession, is then considered.

Constructivism in education and science

The term 'constructivism' is widely used in education, and with a range of meanings (Larochelle, Bednarz, & Garrison, 1998; Phillips, 2000; Potter, 1996; Sjøberg, Forthcoming; Taber, 2009). For example, the term is sometimes used to label interpretive research approaches that explore an individual's own ways of making sense of their lives and experiences (e.g. phenomenography, (Marton, 1981), and where it is recognised that data is necessarily a co-construction between researcher and informant (Kvale, 1996).

Often 'personal constructivism' is distinguished from 'social constructivism', a term which is *sometimes* considered synonymous with 'constructionism' (Burr; Gergen, 1999). This latter approach considers social phenomena to be social constructions, mediated by culture, or brought into being by forms of discourse. Personal construct*ivism* and construct*ionism* are somewhat incommensurable (Kuhn, 1996) approaches, as constructionists would not consider it appropriate or helpful to explore knowledge in the context of an individual's mind (a focus of personal constructivism). Unfortunately the term social constructivism is used ambiguously, so whereas constructionists focus on the interpersonal plane as the building site and location of knowledge, some use the label 'social constructivism' to refer to the social mediation of knowledge that *individuals* come to hold (Marín, Benarroch, & Jiménez Gómez, 2000), i.e., in effect as an alternative emphasis within personal constructivism.

Constructionist approaches have been much discussed in the social sciences, but have tended to be found less appealing in the natural sciences. Notions such as class, disability, gender, prosperity, etc may be readily seen as socially constructed, but natural scientists have tended to consider chemical elements, physical forces, and biochemical pathways and so forth as representing regularities in nature that would exist independently of human beings choosing to study, name or enter into discourse about them (Phillips, 1983).

The 'strong' programme in the sociology of scientific knowledge (Bloor, 1991), that has argued that scientific knowledge is culturally contingent, has been given limited credence by most scientists,

> There are many natural scientists, and especially physicists, who continue to reject the notion that the disciplines concerned with social and cultural criticism can have anything to contribute, except perhaps peripherally, to their research. Still less are they receptive to the idea that the very foundations of their worldview must be revised or rebuilt in the light of such criticism. Rather, they cling to the dogma imposed by the long post-Enlightenment hegemony over the Western intellectual outlook, which can be summarized briefly as follows: that there exists an external world, whose properties are independent of any individual human being and indeed of humanity as a whole; that these properties are encoded in "eternal" physical laws; and that human beings can obtain reliable, albeit imperfect and tentative, knowledge of these laws by hewing to the "objective" procedures and epistemological strictures prescribed by the (so-called) scientific method.
>
> (Sokal, 1996b)

Despite the widespread rejection (or perhaps simply failure to engage with) constructionist perspectives on *scientific knowledge* among natural scientists, the study of how and why *individual* scientists or learners have come to adopt or propose certain ideas and theories has long been considered of interest among science educators as well as historians of science and cognitive scientists (Duschl & Hamilton, 1992).

Constructivism in science education

Forms of personal constructivism, sometimes labelled as 'psychological' (Phillips, 1997) or 'cognitive' (Grandy, 1998) constructivism, offer insights into why an individual came to a particular view or interpreted evidence in a particular way. It is such 'cognitive' constructivist approaches that have formed the mainstream of constructivist thinking in science education research (Taber, 2006b, 2009).

Constructivism has been acknowledged as "something of a research orthodoxy within science education" (Jenkins, 2000: 7), being considered the dominant perspective (Erickson, 2000) or a Kuhnian paradigm (Matthews, 1993; Solomon, 1994). A number of seminal papers published around 1980 (Driver & Easley, 1978; Driver & Erickson, 1983; Gilbert, Osborne, & Fensham, 1982; Gilbert & Watts, 1983; Osborne & Wittrock, 1983) may be considered to have established the basis for a constructivist 'research programme' (Lakatos, 1970) into learning and teaching in science (Taber, 2006b, 2009). Among the basic assumptions of this programme (Taber, 2006a) were:

- Learning science is an active process of constructing personal knowledge.

- Learners come to science learning with existing ideas about many natural phenomena.
- The learner's existing ideas have consequences for the learning of science.
- Learners' ideas exhibit both commonalities and idiosyncratic features.
- It is possible to teach science more effectively if account is taken of the learner's existing ideas.

These principles were derived from a number of sources, especially the works of Bruner (Bruner, 1960, 1966), Ausubel (1961, 1968), Piaget (1929/1973, 1959/2002, 1972; see (Bliss, 1995), Kelly (1963, see (Pope & Gilbert, 1983); and the development of the programme was also strong influenced by ideas from Vygotsky (Vygotsky, 1934/1986, 1978), see (P. H. Scott, 1998).

The establishment of this research programme led to an explosion of interest in eliciting, and characterising students' ideas in science. There are now thousands of papers based on the constructivist approach to exploring learning and teaching in science published in journals, academic books or conference proceedings (Duit, 2007). It soon became widely accepted that students commonly come to science lessons, at all levels and regardless of topic, already holding ideas about, and often at odds with, the science prescribed in the curriculum (Black & Lucas, 1993; Driver, Squires, Rushworth, & Wood-Robinson, 1994). These ideas (given various labels, but here referred to as 'misconceptions', the term widely used in English curriculum guidance) derived from an amalgam of intuitive notions, interpretations of personal experience of the world, 'folk' knowledge, various media sources and previous teaching (Taber, 2007/2008, 2009).

Taking an overview of several decades of research (Taber, 2006a, 2009), carried out in various national contexts, it seems reasonable now to conclude that *some* misconceptions elicited from learners are not strongly committed to, and require little more in the way of a response than being explicitly mentioned and dismissed during teaching (Claxton, 1993; Solomon, 1994). However, other misconceptions have been found to be much more stable and resistant to change (Driver, 1989; Driver & Erickson, 1983; Gilbert & Watts, 1983), and likely - at best - to be temporarily moved into the background by teaching, only to reappear as the preferred way of thinking once the teacher moves on to another topic. Individual learners are likely to hold a range of misconceptions in a topic, and to show different levels of commitment to these, so that some will readily be given-up whilst others may retain their influence despite long-term teaching input (Taber, 1995).

Moreover, some of the most tenacious conceptions are found to be very widespread, and to occur in key science topics. Although careful study of individuals shows that each has a unique set of ideas in a topic, it is none-the-less possible in some topics to identify a common core of misconceptions that are widely shared, and so likely to be reinforced in interactions between students (cf. Solomon, 1987).

The tenacious nature of some student conceptions has been demonstrated in longitudinal studies. In one study pupils were shown, and appeared to accept, that their predictions about the relative brightness of lamps in circuits were wrong. About three months later the researcher found pupils restating their initial (scientifically incorrect) notions, but now citing the demonstration they had seen as *supporting* their misconceptions (Gauld, 1989). Their memories of the evidence had been modified to fit their existing understanding, rather than the other way round. Another example comes from a detailed case study of the progression in thinking of an individual college student as he studied A level (university entrance level in England) chemistry. Over a period of many months his thinking slowly moved beyond the misconceptions he had held at the start of the course (Taber, 2001b). After several further years of studying a science-based course at University, he was re-interviewed about his college chemistry – and it was largely his initial misconceptions that were recalled rather than the new ideas taught during his college course (Taber, 2003). These and many other studies have demonstrated that not only are students' existing ideas often significant for learning, but that long-term conceptual change may require carefully planned pedagogy that goes well beyond just telling or showing students their ideas are wrong.

Constructivist pedagogy in science education

The constructivist programme of research into learning in science has led to much discussion of the nature of suitable pedagogy that takes into account learners' existing thinking (Driver & Bell, 1986; Fensham, Gunstone, & White, 1994; Mintzes, Wandersee, & Novak, 1998; Taber, 2009).

Constructivist thinking about teaching science may be considered to comprise of two aspects, concerned respectively with the building up of new knowledge based on the cognitive resources students bring to class (an 'aufbau' princple), and responding to students' tenacious ideas that are inconsistent with intended learning (a 'flip-flop' principle).

The 'aufbau' (build-up) principle tells teachers that many of the ideas met in school and college science are too complex to be understood and accepted immediately by many learners. Teachers therefore need to build-up an understanding by starting from ideas and experiences familiar to the learners, and using these to support the incremental development of new understandings. To do this effectively teachers have to be aware of size of 'learning quanta' that the human cognitive system can typically process at any one time, and the typical timescale for consolidating new learning before it becomes sufficiently integrated into a learner's knowledge systems to be robust enough to support further new learning (Taber, 2005b). Therefore an important part of teachers' professional knowledge is a good understanding of the cognitive resources in place for constructing new knowledge. A key feature of pedagogy based on this 'aufbau' approach is regularly eliciting the students' current ideas and understanding, as these provide the resources for building new understanding. This is clearly a 'constructivist' model of teaching, that is applicable well beyond science instruction, and based on basic principles that were already well-established in (for example) Gagné's (1970) learning theories before the notion of constructivism was popularised in science education.

However, where the existing cognitive 'resources' of learners include well-established conceptions about topics that are actually inconsistent with the material prescribed in the curriculum, these 'misconceptions' may often act more as barriers to intended learning, rather than being suitable as foundations for the target knowledge (Chi, 1992). It has been argued that when one way of thinking is habitual, and seems unproblematic to the learner, then conceptual change is difficult to achieve as it requires *both* becoming familiar with a novel way of thinking about a topic, and having sufficient reason to 'switch' allegiance to the new understanding (Thagard, 1992).

Here the aufbau principle is insufficient, and a form of 'catastrophic' learning is needed. A catastrophe, in this sense, occurs when teaching is able to facilitate a learner's thinking to move over the 'cusp' between alternative ways of understanding a topic (Boyes, 1988). As it is known that once an individual has several ways of 'seeing' a situation, suitable cues can initiate a gestalt-switch back or forth (Kuhn, 1996), a useful analogy here is the flip-flop - a device (used in electronics) with two distinct stable states that can be switched between states by a sufficiently strong input signal.

There has therefore been much debate in science education into how to 'change students' minds' about natural phenomena, and so to convince them of the value of the scientific models that are represented in the curriculum. Again, a starting point for pedagogy would be eliciting students' existing ideas, but then the teacher must find ways to either challenge existing notions, or find ways to conceive students' existing notions as possible 'intermediate' conceptions upon possible conceptual trajectories towards the prescribed target knowledge found in the curriculum (Driver, 1989). The teacher needs to understand learners' existing ideas well enough to appreciate what would form a rational basis on which students may come to revise their thinking (Posner, Strike, Hewson, & Gertzog, 1982), a process considered to be in principle similar to that occurring when scientists adopt a new theory (Thagard, 1992).

Suggested approaches include creating cognitive conflict by demonstrating students' ideas lead to evidently false predictions, scientific testing of ideas in the laboratory; using thought experimentation to help students test out the consequences of their ideas and compare these with their own experiential knowledge base; using sequences of bridging analogies, to show how apparently counter-intuitive ideas actually make sense in terms of more easily appreciated analogues; using various kinds of models and simulations to help learners visualise the mechanisms behind scientific explanation e.g. (Bryce & MacMillan, 2005; diSessa, 1993; Driver, Leach, Scott, & Wood-Robinson, 1994; Gilbert & Newberry, 2007; Gutwill, Frederiksen, & White, 1999; Helm, Gilbert, & Watts, 1985; Rea-Ramirez & Clement, 1998; Russell & Osborne, 1993; Smith, diSessa, & Roschelle, 1993; Wightman, Green, & Scott, 1986; Zietsman & Clement, 1997).

So constructivist pedagogy in science education invariably starts from an exploration of students' current thinking, and various techniques have been developed for this, some of which are compatible with classroom use by teachers as well by researchers (Taber, 2005; White & Gunstone, 1992). Much research is available to inform teachers of common alternative conceptions, but as each individual learner is unique, effective approaches rely upon a dialogic approach where the teacher takes the students' views into account and persuades them of the power of the scientific models (Mortimer & Scott, 2003). In some cases this sufficiently informs the normal rhetoric of the teacher's exposition to help students construct the 'common knowledge' of science (Edwards & Mercer, 1987; Lemke, 1990), and recreate their own personal versions of the theoretical entities constructed in science (Ogborn, Kress, Martins, & McGillicuddy, 1996).

However, where students are already strongly committed to ideas inconsistent with the target knowledge it is likely that significant conceptual change will be dependent upon the teacher engaging the students in a range of active learning tasks designed to have them explore and question their existing thinking. Research has suggested that this type of teaching starts with the elicitation of existing ideas, which then forms the basis of detailed planning for teaching the topic (Driver & Oldham, 1986; Johnston & Driver, 1991; Russell & Osborne, 1993).

Criticism of constructivist approaches to pedagogy

Although constructivism in education has been based on the ideas of such respected thinkers as Piaget, Vygotsky, Bruner and Ausubel, and although it has dominated research in science education for some decades, there has also been strong criticism of constructivist-informed pedagogy. In the United States constructivist approaches were characterised by Cromer as leading to a content-free science education, where opportunities for learning-by–enquiry take precedence over learning accepted scientific ideas, and where children's own ideas are considered to be of equal validity to those of science (Cromer, 1997). It is certainly the case that in the US there has been a strong emphasis on 'inquiry' in school science (National Research Council, 1996), but mainstream constructivist thinking in science education has recommended eliciting learners' ideas because they are the necessary starting point for learning schools science, rather than viable alternatives to understanding nature (Taber, 2006b, 2009). Indeed, one of the seminal figures in the field saw constructivist thinking as strongly showing why discovery learning that was not carefully guided was *unlikely* to be effective (Driver, 1983). Other critics have accused constructivists of building their pedagogy upon a philosophical position that is relativist and so in essence anti-scientific (Scerri, 2003).

Relativists suggest that science's claim to objective knowledge is an illusion as all human knowledge is inevitably judged relative to the prevailing cultural norms and values, and so is historically contingent (Bloor, 1991). This position takes support from Kuhn's (Kuhn, 1996) writings about the incommensurability of different scientific world-views (paradigms) and Feyerabend's (epistemological) anarchistic view of 'scientific method' (Feyerabend, 1988). Modern science, according to this view, might have been quite different had it developed under different circumstances.

To most scientists, such a view is nonsensical as science is based on the application of logic to objective evidence, and its outputs (theories etc) only gain general acceptance by wide corroboration of results and the persuasion of international community. It is this view that is reiterated in Sokal's comments quoted above. The quotation comes from a paper published in the journal *Social Text*, that was written as a parody to test whether a cultural studies journal would "publish an article liberally salted with nonsense if (a) it sounded good and (b) it flattered the editors' ideological preconceptions" (Sokal, 1996a). Sokal suggested that the latest developments in quantum physics supported a view of a subjective universe, and accordingly argued for a new 'liberatory' science, that required a novel emancipatory mathematics. Sokal deliberately supported the 'argument' with irrelevant and inaccurate references to modern scientific ideas. The journal authors presumably did not see the joke, and their referees failed to spot that the 'argument' had little basis in logic or evidence.

The Sokal hoax unfortunately provides comfort to those within science who see the debates about the extent to which a social science can be objective as of no relevance to natural sciences, as well as potentially undermining the work of those pointing out serious issues of unequal access to the institutions of science(e.g., Harding, 1993; Kelly, 1987). In the US, in particular, a notion of 'science wars' (Matthews, 1998) has real currency as scientists associate relativism with trends that are considered dangerous, such as patients with serious medical conditions preferring untested new age therapies to established clinical treatments, or arguments that if science does not offer absolute knowledge then the 'current' scientific theory of evolution by natural selection should not taught in school science in preference to creationism or 'intelligent design'.

Scerri (2003) has accused US constructivist science educators of basing their pedagogy on a relativist base, because prominent US science educators such as Bodner (1986) have cited the 'radical constructivism' of Ernst von Glasersfeld (1989a) as underpinning their thinking. This 'radical' constructivism, although itself developed form Piaget's ideas (Glasersfeld, 1989a), is said to be anti-realist and so anti-scientific.

Similar criticisms have been made by Matthews (1994) - who has, in particular, attacked the influence of constructivist researchers on the science curriculum in New Zealand. This particular development was the focus of considerable attention (Bell, Jones, & Car, 1995), including coverage in mainstream media (Saunders, 1995). The New Zealand curriculum document (Ministry of Education, 1993) was informed by decades of funded research in New Zealand into aspect of learning in science (Bell, 2005), and avoided detailed prescription of science topics. The curriculum document (Science in the New Zealand Curriculum) does not explicitly discuss constructivism as a model of learning and teaching (Ministry of Education, 1993). However, one of the general aims of science education, inter alia, is given as "is to advance learning in science by…portraying science as both a process and a set of ideas which have been constructed by people to explain everyday and unfamiliar phenomena" (Ministry of Education, 1993: 9); and one feature offered of an "an inclusive curriculum in science" is (again, *inter alia*) that it "provides opportunities for girls to…examine the historical and philosophical construction of science" (Ministry of Education, 1993: 11). What seems more significant is the focus on active learning, learning of process skills, group work, model building and the like *rather than subject content*. The curriculum document offers examples of teaching and learning contexts for meeting the curricular aims, but does not set out target knowledge in the form of detailed specifications of science topics to be taught. Whilst this is certainly compatible with a constructivist approach, it is neither necessary nor sufficient to ensure teaching that is broadly constructivist. Indeed, the extent to which teachers in New Zealand have taken advantage of the flexibility provided to design schemes of work to meet the needs and interests of their own students has been questioned (Coll, 2007).

Matthews, like Scerri, particularly objected to the relativist leanings he identified in the ideas underpinning constructivist pedagogy (Matthews, 1993). Other critics, less opposed to constructivism *per se*, have also commented on the apparently confused epistemology supporting the constructivist research programme in science education (Phillips, 1995).

These are important criticisms. It should be noted however that although scientists and philosophers of science generally believe that science does provide objective knowledge, and is in some sense making progress (i.e. that over time scientific knowledge becomes more reliable), since foundational philosophies of science (positivist approaches based upon pure empiricism or rationalism) have been discredited, the issue of exactly *how* science achieves this has been the subject of ongoing academic debate (Lakatos, 1970; Laudan, 1984; Popper, 1989; Toulmin, 1961). Indeed, it might be suspected that this lack of an agreed basis for a belief in scientific progress contributes to the rather defensive response to any suggestions of relativism in science, or science education.

Before leaving this debate, it is useful to note (a) that the 'psychological', 'pedagogic' or 'cognitive' constructivism that is widely espoused in science education (i.e. how individuals build up their personal knowledge) need *not* be associated with a particular view of how science develops its *public* knowledge; and (b) that Glasersfeld's radical constructivism that is often seen as a relativist villain does *not* deny a single external reality, but only the possibility of assured knowledge of its true nature (Glasersfeld, 1989b, 1992). In this sense Glasersfeld is best seen as an instrumentalist, i.e., holding a position much less objectionable to most scientists which considers scientific theories and models primarily as useful tools for making sense of the universe that should be given credence as long as they fit with the evidence of our experience (Glasersfeld, 1990).

Despite the strength of objections raised against constructivist teaching approaches in the US and NZ, the adoption of constructivist ideas in official guidance to English science teachers appears to have attracted little comment or public debate. This in itself is worthy on consideration.

Official pedagogic guidance for science teachers in England

The 'guidance' considered here comprises three main sources: requirements for initial teacher preparation courses, officially sanctioned model schemes of work, and materials produced through a major government initiative (a 'national strategy') offering funded profession development opportunities for teachers.

In 1998, the Government prescribed a National Curriculum for Initial Teacher Education that set out what new teachers had to be taught (Department for Education and Employment, 1998). The contents can be considered to include a model of pedagogy being recommended to new teachers. (This National Curriculum was superseded in 2002 with the introduction of standards for qualified teachers (Department for Education and Skills & Teacher Training Agency, 2002).) In the same year (1998) the government's Qualifications and Curriculum Agency issued a 'model' scheme of work for primary school science, followed two years later (2000) by a model scheme of work for lower secondary science.

In 2002 the Government's ministry of education (the Department for Education and Skills, as it was then) introduced a major professional development initiative aimed at 'raising standards' at lower secondary level, called the *Key Stage 3 National Strategy* (which later became the *Secondary National Strategy*), henceforth 'the Strategy'. Science, as a core curriculum subject had its own strand of the strategy. A key feature of the strategy was a 'Framework' for teaching the science curriculum in the three years of the lower secondary school (Key Stage 3 National Strategy, 2002b). This organised the teaching of the 37 topics of curriculum around five 'key ideas' – cells, energy, forces, interdependence, particles (Grevatt, Gilbert, & Newberry, 2007; Kind & Taber, 2005).

The Framework was the central component of the Strategy science strand, which was delivered through a system of regional 'Strategy Advisors' offering courses for teachers. Some courses were intended to be attended by representatives from all state school science departments (who would then be expected to pass on key ideas to colleagues through departmental sessions), and other courses were offered on an elective basis so that schools could prioritise their particular training needs. A variety of forms of supportive documentation were provided to support the training, and much of this material was made generally available through official websites (DCSF, 1995-2008, 1997-2008).

During the second year of the initiative schools were offered six days of training (i.e., funding to cover 6 days of staff release) in the areas: misconceptions in science; scientific enquiry; assessment in science; literacy in science; planning progression; and effective lessons (Key Stage 3 National Strategy, 2002a). So the topic of 'misconceptions' was seen as a key area for science teacher development. Further topics were included in subsequent years, including specific guidance on teaching key topics areas.

As the initiative was based on centrally designed training, delivered by local advisors, much of the training was scripted, with the advisors being provided with presentation materials, and being given instructions on which points to make supported by examples they might use. Whilst this might not seem the basis of effective pedagogy for teacher development (Boyle, Lamprianou, & Boyle, 2005; Garet, Porter, Desimone, Birman, & Yoon, 2001), it does offer a useful record of the basic content of the training sessions.

Constructivist principles incorporated in official English guidance

Key aspects of constructivist thinking were reflected in these sources of officially recommended pedagogy. According to the National Curriculum for initial teacher education, 'trainees' were to be taught both "that pupils' own ideas about areas of science will often differ from accepted scientific ideas, and how to understand possible origins of pupils' misconceptions, and how they can be addressed" (Department for Education and Employment, 1998). Examples of common 'misconceptions' were cited: "thinking that, in a simple circuit, the current in the return wire is less than the current in the wire to the device; thinking that plants breathe in carbon dioxide and breathe out oxygen". Trainees also had to be made aware that "some scientific ideas, e.g., an object moving at a steady speed in a straight line has no net force acting on it, are counter-intuitive in that they seem contrary to everyday experience". Trainees were to be taught how scientific arguments and evidence might be understood differently from the pupils' perspectives,

> that pupils' incomplete understanding of scientific ideas sometimes prevents them from making distinctions between separate scientific ideas; … that some illustrations and examples may require a general knowledge which some pupils may not possess, e.g. pupils in urban schools may be less familiar with animal hibernation or seasonal variation
>
> (Department for Education and Employment, 1998)

The document required trainees to be taught how "using models, analogies and illustrations in science teaching is a powerful way to explain complex scientific principles to pupils", but also that, *inter alia*, "all analogies have limitations" so that "some pupils may confuse representations with the scientific ideas they aim to explain". Trainees were to be taught that teaching "activities must be designed to build on pupils' previous knowledge and understanding" (Department for Education and Employment, 1998).

The model Schemes of Work issued through the government's Qualifications and Curriculum Authority also demonstrated the application of constructivist principles. So it was recommended that teachers begin the Year 4 (i.e., 8-9 year olds) topic on solids and liquids by "elicit[ing] children's existing knowledge of materials". The teachers "need to take account of what this introductory work shows about children's knowledge and understanding of materials in their short-term planning for this unit" (QCA, 1998).

Some of the units in the lower secondary scheme included reference to common alternative conceptions reported in previous research, for example that "a common misconception is that activity gives you energy because it makes you healthier – and so more able to do more activity" (QCA, 2000a).

The Framework document, which was intended to act as the basis for pedagogy in lower secondary school science ('Framework for teaching science: years 7, 8 and 9': Key Stage 3 National Strategy, 2002b), highlighted the significance of 'misconceptions',

> Some scientific ideas are difficult because they involve the learner in abandoning previous beliefs – for example, a belief that heavy objects fall faster than light ones. Pupils will not necessarily be convinced by a demonstration. They are likely to see what they want or expect to see … or they will try hard to find fault with the test in order to hang on to their belief.
>
> (Key Stage 3 National Strategy, 2002b: 14)

The importance of making learners' ideas explicit, so that they could be challenged if appropriate, was emphasised,

> Teachers have to challenge pupils' thinking and give them new perspectives from which to view the evidence through a range of activities and frequent reinforcement. Pupils often need to articulate the conflicts that exist in their minds. Drawing out their thinking and talking about their difficulties in abandoning their beliefs is a key role for an adult in the room, such as the teacher, a technician or a teaching assistant attached to the science department.
>
> (Key Stage 3 National Strategy, 2002b: 14-15)

Moreover, the interactive and dialogic nature of effective teaching was emphasised (Mortimer & Scott, 2003), with teachers expected to be sensitive to and responsive to learners' ideas during teaching,

> "During every lesson you absorb and react to pupils' responses, …Where you notice any difficulties, misunderstandings or misconceptions, you can adjust your lesson and address them straight away, if necessary continuing in the next lesson or two. … Plenary sessions are also a good time to firm up short-term assessments by asking probing questions to judge how well pupils have understood new work and to check again for any misunderstanding or misconceptions."
>
> (Key Stage 3 National Strategy, 2002b: 50)

The Strategy unit on Misconceptions in science explained that "the term 'misconception' is used when referring to the commonly held beliefs that pupils hold that are at variance with the accepted scientific view" (Key Stage 3 National Strategy, 2002d: 1), which "may be social (held by a large proportion of the population) or personal, and are developed through everyday talk" (Key Stage 3 National Strategy, 2002d: 10). A list of common 'misconceptions' was provided (Key Stage 3 National Strategy, 2002d: 71) and teachers attending the training were informed that 'misconceptions' (Key Stage 3 National Strategy, 2002d: 10):

- Have been constructed from everyday experiences
- May be linked to specialist language
- Can be personal or shared with others
- Explain how the world works in simple terms
- May be inconsistent with science taught in schools
- Can be resistant to change
- May inhibit further conceptual development

Among the 'main messages' that teachers were expected to take away from the course (Key Stage 3 National Strategy, 2002d: 69), were:

- Pupils (and many adults) frequently hold misconceptions/alternative conceptions/alternative frameworks relating to science. These can be close to or widely different from the accepted scientific view.
- Misconceptions can be resistant to change.
- Teaching needs to take account of pupils' misconceptions by: identifying them; devising teaching programmes that correct the misconceptions.

Although the *Misconceptions in science* unit was just one element of an extensive staff development initiative, its main messages were reflected in various other strategy training units and support materials. A unit on 'progression' in learning science emphasised that "we need to elicit pupils' understanding (and misconceptions) at the start of a unit and match our teaching accordingly" (Key Stage 3 National Strategy, 2002e). A unit on scientific enquiry reiterated that "science is often counter-intuitive" (Key Stage 3 National Strategy, 2002b). A unit on 'pedagogy and practice' informed teachers that "Good teaching results when teachers: focus and structure their teaching so that pupils are clear about what is to be learned and how, and how it fits with what they know already; actively engage pupils in their learning so that they make their own meaning from it" (Key Stage 3 National Strategy, 2003).

Training units on key topics also reiterated the constructivist view of teaching and learning in specific contexts (Key Stage 3 National Strategy, 2002c, 2003a, 2003c, 2003d, 2003e, 2003f, 2003g, 2003h, 2003i, 2003j, 2003k, 2004):-

- learners build up their understanding based on previous learning
- learners have everyday meanings for technical words
- learners often come to class with misconceptions about the topics to be taught
- there are common misconceptions exhibited by many students
- planning should incorporate responses to common misconceptions
- some misconceptions may derive from misunderstanding teaching
- teachers need to be aware of learners' misconceptions if they are to be challenged
- eliciting learners' ideas is an important step in teaching

The nature of official constructivist pedagogy in the English curriculum context

Basic principles of constructivist thinking have then been incorporated into official guidance to science teachers in England over the past decade. Science teachers in England are expected to be aware that learners construct their own understandings of the natural world, which often deviate from the curricular models in the school curriculum, and which will interfere with learning of target knowledge. Teachers are expected to both (a) be aware of common 'misconceptions' and build activities to challenge these into their planning, and (b) include elicitation activities to diagnose the specific misconceptions among particular classes, and then modify their teaching to respond as seems appropriate. Furthermore, teachers are expected to appreciate something about possible origins of learners' misconceptions (in terms of everyday language, potential to misunderstand teaching etc). In particular, teachers are encouraged to use models and analogies to make the unfamiliar familiar (Taber, 2002), whilst ensuring that students appreciate the limitations of those models so that they do not act as sources of new misconceptions (Taber, 2008). In this teaching approach, at least, constructivist pedagogy can reflect the instrumentalist approach to scientific theories and models that is a feature of Glasersfeld's (1990) 'radical' constructivism.

It seems that constructivism, so long the 'paradigm' in science education research (Erickson, 2000; Jenkins, 2000; Matthews, 1993; Solomon, 1994), has been adopted as a major feature of official pedagogy in England. Yet this seems to have occurred without the widespread and public criticism that accompanied the advocacy of constructivism in science education in the US, or the introduction of a constructivist influenced curriculum in New Zealand.

It is possible to suggest several contributing factors that may in part explain this difference. For one thing, guidance is, in principle at least, not binding but only 'recommended'. Of course, this is a simplistic view, as - in practice - teachers and departments that are considered to be under-performing are likely to be put under pressure by school management to adopt the recommended approaches. None-the-less, being told 'we *suggest* you do this, and will expect you to justify your decisions if you do not do so' is less of an affront to teachers' professionalism than 'we require you to do your job this way'.

A second potentially significant factor is that the advice, which has been offered without strong philosophical (or even detailed explicit psychological) underpinning, may be largely unobjectionable to most teachers. Prior to the introduction of a mandated National Curriculum there was a period of great professional freedom, and widespread curriculum development in England (Jenkins, 2004), where many science teachers were involved in action research initiatives exploring and adopting new ideas in pedagogy (Parkinson, 2004). In particular, highly influential constructivist research and curriculum development projects at both secondary (*Children's Learning in Science Project*: (P. Scott, Dyson, & Gater, 1987) and primary (*Science Processes and Concept Exploration Project*: Russell & Osborne, 1993) levels worked collaboratively with teachers, and had been widely reported through practitioner meetings, periodicals and published course materials.

Another possible factor is the curriculum context into which the official guidance has been injected. Whilst the essence of the pedagogic guidance is certainly constructivist, it was introduced into a setting where a highly detailed prescribed science curriculum had to be 'delivered'. The *recommended* teaching approaches, although in principle based on facilitating active learning and teacher sensitivity to learners' ideas, could only be applied to the extent that they allowed teachers to 'cover' the extensive content they were required to teach. This imposed a strong constraint on how constructivist approaches could be applied. Open-ended enquiries (of the type widely advocated, and vociferously criticised, in the US) were not consistent with a narrow curricular model of scientific enquiry that was taught and assessed in the National Curriculum (Taber, 2008). Opportunities for spending time exploring students' interests and accommodating local conditions (a feature of the NZ curriculum) were sparse when there were so many mandatory topics to cover (unlike the NZ curriculum).

In practice, then, the officially recommended pedagogy involved elements of constructivist practice grafted onto packed and highly specified teaching schemes. Indeed some of the official guidance seems designed to imply that eliciting students' ideas and then teaching accordingly (to borrow an aphorism form Ausubel, 1968) involves little more than tweaking of existing approaches, e.g.,

> A common misconception is that plants obtain their food from the soil. It is worth establishing that this is not the case early on in the teaching sequence, and reinforcing this idea throughout the unit.
>
> (QCA, 2000b: 3)

There are certainly mixed messages in the guidance, as although the tenacious nature of some misconceptions is pointed out (Key Stage 3 National Strategy, 2002b: 14), other guidance suggests to teachers that "the first few lessons [of a topic] can be organised to deal with the range of understanding elicited" as "checking understanding and dealing with it at the start of a unit takes relatively little time, reduces unhelpful repetition of earlier work, thereby saves teaching time and helps maintain pupil motivation" (Key Stage 3 National Strategy, 2002e).

To illustrate this point with one example, one of the most common misconceptions reported in research involves a belief that a moving object must be subject to a force (where according to physics a moving object subject to no overall force will continue to move indefinitely, but without any change in velocity). This misconception has been reported in various national contexts, and throughout educational levels. Prior to the introduction of the English National Curriculum, Gilbert and Zylbersztajn (Gilbert & Zylbersztajn, 1985) reported that 85% of a sample of 125 14-year old UK pupils held this misconception. One US study reported that 93% of high school students tested demonstrated this misconception before they were taught Newtonian physics, and that "80% of the students retained this belief even after finishing the course" (McCloskey, 1983: 122).

The Strategy materials appropriately inform teachers that "many [pupils] will wrongly associate constant force with constant speed", but the advice to "take the opportunity to challenge any pupil's association between force and constant speed" (QCA, 2000c: 4) would seem woefully inadequate in view of the extensive research evidence reporting how tenacious this misconception is.

Discussion

The present paper has offered an account of a key feature of official cuuriculum guidance issued to science teachers in England over the past decade. It has been demonstrated that constructivist ideas have been adopted as part of official pedagogy in English schools, something that the author broadly welcomes, having himself been an advocate of this perspective in science teaching (Taber, 2000, 2001a, 2006b). Indeed this provides a welcome case of one area where academic research is certainly linking with teacher thinking and classroom practice (de Jong, 2000).

However, this raises a number of important issues. For one thing, it is only possible to speculate how constructivist thinking has managed to become so well embedded in official guidance without any major debate (compared with the US and NZ). I have mooted some candidate factors here, but the issue deserves closer examination as it clearly raises a number of questions. Perhaps, as a result of their training and experience, and a tradition of curriculum development, science teachers in England are able to recognise the approach being recommended as having merits and see little reason to question it. Whilst the present author would be encouraged if that were so, there may be alternative interpretations:

- perhaps the vast expenditure on official guidance is having very little effect, and science teachers are largely ignoring it (Taber & Bektas, In press)?
- perhaps there has been a major switch in teacher expectations since the 'heady' days of the 1980s so that most teachers in England now expect to be told what to teach, and how to teach it (Donnelly & Jenkins, 2001)?
- perhaps the version of constructivism offered in the guidance has been so sanitised to appear not to conflict with the 'delivery' of the prescribed science content, and does not appear to ask teachers to radically change their practice?

The latter possibility may be reflected in a case study of teaching beliefs and behaviour carried out by Kaymaz (2007). The case was a teacher recognised as an excellent practitioner who was interviewed and observed teaching secondary science lessons. Kaymaz reported that the teacher's reported beliefs and observed teaching practice both strongly reflected constructivist principles – although when asked the teacher reported not recalling having come across the term 'constructivism'.

The English science curriculum has now been revised (QCA, 2007a, 2007b) in response to the widespread criticisms it has faced (Cerini, Murray, & Reiss, 2003; HCSTC, 2002; J. Osborne & Collins, 2000). The new curriculum has been informed by principles intended to offer a more engaging and personally meaningful science-for-all (Millar & Osborne, 1998). If such changes in curriculum are to have the desired effect then it is important that classroom practice undergoes quite radical changes to adopt new pedagogies (Levinson, 2007), and reflects constructivist principles at its core, not at its edges.

In view of the quite radical changes in science curriculum being introduced (QCA, 2007a, 2007b), themselves the focus of public comment and criticism (Gilland, 2006), there is clearly a need for research which can explore how teachers understand the official pedagogical guidance, how they coordinate advice deriving from official agencies in relation to their existing professional knowledge, and how (if at all) they enact the pedagogic principles in their classroom practice.

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