The version of record is: Taber, K. S. (2018). Pedagogic Doublethink: Scientific Enquiry and the Construction of Personal Knowledge Under the English National Curriculum for Science. In D.W. Kritt (Ed.), ***Constructivist Education in an Age of Accountability.*** Cham: Palgrave Macmillan.

Pedagogic Doublethink: Scientific Enquiry and the Construction of Personal Knowledge Under the English National Curriculum for Science

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Abstract

The English National Curriculum (for 5–16 year olds) for the science taught in English schools has had unintended as well as planned effects. There has been extensive government involvement in the professional work of teachers through inspection regimes, offering direction on the nature of formal assessment, and emphasising the outcomes of high status tests as public markers of educational quality. The chapter considers where these efforts have supported teachers in meeting widely accepted aims of science education, and where they have—often inadvertently—restricted good teaching practice and undermined efforts to teach in accordance with the principles of constructivist educational theory,: working against teachers' flexibility to respond to the needs of students, undermining meaningful enquiry teaching, and restricting effective teaching about socio-scientific issues.

As a curriculum area, science would seem to be particularly suited to constructivist approaches to education. There are at least three distinct lines of thought that might lead to this conclusion. For one thing, much of the work that was part of the explosion of interest in science education as a research area (around the 1970s and 1980s) was undertaken from a constructivist stance on student learning and thinking.

Secondly, scholarship into such areas as the history, philosophy, and psychology, of science suggests that the way in which science itself proceeds needs to be understood from a constructivist perspective. Finally, there has in recent decades been a strong international impetus to increase engagement with authentic enquiry—that is in terms of engaging students in the process of constructing understanding through the interplay of empirical work and the personal and social building of conceptualisations of the natural world.

Yet in practice more traditional notions of the science curriculum—as a body of pre-processed knowledge to be communicated through teaching and assessed in high-stakes tests—can often be firmly established in the minds of key stakeholders, such that even when lip-service is paid to, for example, the importance of teaching about the nature of science or the need for enquiry-based science teaching, there is considerable systemic resistance to real changes in the nature of science teaching and learning.

This chapter explores these issues—the drivers for a more constructivist approach to science education and the sources of inertia retarding change. The chapter draws upon the situation in England where the relationship between official guidance to teachers and teacher educators on the one hand and curriculum and assessment policy on the other sends out mixed messages, such that it is not fanciful to suggest teachers need to adopt a kind of doublethink in order to cope with the contrary expectations they are subject to. That is, teachers are pressured to adopt and act on a range of expectations that in practice are mutually inconsistent. The English context has been particularly rich in government-sponsored advice to teachers on how to undertake their professional work, but issues raised here are reflected to varying degrees in many other contexts: not least in the debates about the merits of what are seen as progressive and traditional approaches to teaching in the United States.

Constructivism and Research in Science Education

The strength of constructivist thinking on science education as a research field from the 1970s onwards was such that it became seen as a dominant perspective—or even the equivalent of a paradigm of the kind Kuhn (1970) posited in "normal" periods of science (Fensham, 2004; Taber, 2009). Researchers informed by the constructivist aspects of Piaget's (1970/1972) programme exploring the development of thinking in children and adolescents (e.g., Driver & Easley, 1978), and by Kelly's (1963) personal construct theory (e.g., Gilbert & Watts, 1983), were highly influential in shifting the dominant focus of research away from the general patterns of thought that students of particular ages were capable of demonstrating (i.e., the core focus of Piaget's own work) to exploring the specificity and variety in student thinking about particular science topics. Work exploring alternative conceptions or alternative frameworks, and later on conceptual change in science, became major foci of educational research activity, leading to a vast literature (Duit, 2009). Some of these studies clearly championed constructivist principles, some nominally name-checked constructivism as an assumed perspective, and much reported work that at least implicitly relied on assumptions about the educational significance of the personal and sometimes idiosyncratic nature of students' ideas (Taber, 2009). Indeed, one criticism raised was that at the height of its influence, constructivism was so dominant that it distorted the field of science education to the exclusion of other valuable complementary perspectives (Solomon, 1994).

The extent to which this research activity engaged with constructivist thinking in any depth was variable. One of the most influential theorists was Glasersfeld (1989), who developed a position labelled as radical constructivism, which adopted a strong epistemological position on the nature of human knowledge as necessarily due to personal construction. For Glasersfeld the external physical world constrains the sensory information available to make sense of experience (e.g., a person cannot walk through brick walls), but perception involves interpretation in making sense of sensory information—the human cognitive apparatus necessarily "re-codes" sensory input so what reaches consciousness is a much processed signal (Taber, 2013b). A person's only meaningful reality is that (necessarily channelled and interpreted) experience, as we can have no direct unmediated engagement with the external world. This theoretical perspective initiated much debate from those who engaged with the philosophical positions underpinning constructivist work (Matthews, 1998; Scerri, 2003, 2012; Taber, 2010c).

Most of the studies in science education, however, did not explicitly explore such issues, but relied more on a psychological grounding for constructivism that did not engage with arguments about epistemology in general (the origins and grounds of knowledge), but only with issues of how students developed their ideas. [1] This was based on the clear empirical evidence that (1) students attending science classes would commonly arrive with ideas about topics inconsistent with the curriculum content they were to be taught, and that, particularly in some topics, (2) they were almost as likely to demonstrate alternative conceptions after being taught the topic as before, albeit that their post-instruction thinking sometimes reflected an interaction between pre-instructional thinking and teaching (Gilbert, Osborne, & Fensham, 1982).

A key claim made by some researchers was that alternative conceptions explored in their work were highly stable and tenaciously retained, and so not readily changed by teaching. This claim was subject to some criticism (e.g., Claxton, 1993) but has—with an important qualification—been supported by much research since. Students' alternative conceptions vary across a range of dimensions (Taber, 2014), and some are quite labile and not particularly significant for learning. However, some common alternative conceptions have

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[1] It could be suggested there is a sleight of hand here, as such a distinction could be considered to presume some fundamental difference between how individual people develop beliefs about the world and how science comes to knowledge. If the difference between how a schoolchild comes to adopt a particular conception of some aspect of nature (e.g., there is no gravity in space because there is no air), and how a scientist comes to adopt a particular conception of some aspect of nature (e.g., that the observed speed of light is invariant for all observers) is a matter of degree (e.g., levels of skills and expertise) rather than due to the operation of different cognitive processes then there is no in principle difference between the fallibility of a child and that of the community of science. The adoption of a constructivist perspective requires the abandonment of traditional notions of (scientific) knowledge as true, justified belief (Taber, 2013b).

been shown to readily become well established in student thinking and then very difficult to modify (Gilbert & Zylbersztajn, 1985; Taber, 2013a).

Influences of Constructivist Research on Science Teaching Practice

Much of the research exploring how students (of various ages, in diverse national contexts) understand a wide range of science topics was justified as educational research in terms of being useful to inform curriculum design and classroom practice. The argument was that if science teachers had a better understanding of the ways in which students already understood topics and how they commonly interpreted teaching, then science teachers would be better prepared to spot such patterns of thinking and channel student thinking towards the target understandings in the curriculum. Teachers could challenge common alternative conceptions and develop specific pedagogy to persuade students towards desired conceptual change (Clement, 1993). This was an extensive research area that was not limited to science education researchers (although science concepts were common foci for work on conceptual change undertaken from within more general fields exploring learning such as general psychology/cognitive science/ learning sciences).

The research into students' ideas therefore fed into work on pedagogy and curriculum development (Driver & Oldham, 1986; Russell & Osborne, 1993). Teachers were encouraged to begin a topic by eliciting student thinking, so as to make explicit students' existing conceptions. This allows teachers to take on those ideas and argue (preferably with suitable empirical demonstrations) for why the scientific models and concepts work better. This pedagogy could have the potential to encourage students to form new potentially unhelpful ideas during the elicitation activity (Claxton, 1993), and to then feel they should commit to and defend those ideas they have been asked to share (Claxton, 1986), and so may seem counter-productive. Yet research suggests that many of the most tenacious alternative conceptions have their origins in implicit knowledge that people develop from experience and which is automatically drawn upon during perception/cognition without conscious control or awareness (DiSessa, 1993; Smith, DiSessa, & Roschelle, 1993). Given that, allowing student thinking to continue to operate at a tacit level without being challenged is likely to allow it to continue to operate insidiously, often without the learner having any awareness that their way of making sense of teaching is quite different to that intended by the teacher.

Influences from Science Studies Scholarship

Another area of relevance relates to the various strands of science studies that have explored the processes by which science produces knowledge. This is a vast area of scholarship, which cannot be done justice here, but some examples can be offered. The work of Thomas Kuhn (1970), for example, emphasised the importance of being socialised into a particular way of thinking about the natural world for channelling how evidence is understood, and the substantial challenge of undergoing "paradigm-shifts" between scientific world views. Kuhn did not suggest science was irrational, but did argue that it was difficult for any scientists trained within a particular tradition to step outside that framework and look at evidence from a neutral standpoint—a point that applies to human experience, generally, given that to be fully human is to have been encultured within some worldview or another (Geertz, 1973). Other scholars have built upon this work to demonstrate how scientists' commitments to what now seem clearly inadequate ideas may have been perfectly logical at the time (Thagard, 1992).

Kuhn also highlighted the role of the creative, imaginative aspect of scientific work that has been critical in many scientific discoveries (Koestler, 1978/1979; Miller, 1986). This has been widely acknowledged by some scientists but tends to be underplayed in science education in relation to the logical aspects of scientific work (Kind & Kind, 2007; Taber, 2011b). Forming and testing ideas is only part of the scientific process, as science is a community-mediated activity and the scientist has to convince her or his peers that their ideas are valuable as descriptions of nature or as explanatory tools. Science therefore has a very strong rhetorical aspect (Gilbert & Mulkay, 1984), something that has been reflected in recent years by active research exploring the role of argumentation in science learning (Erduran, Simon, & Osborne, 2004).

Moreover, there has been a strong focus within some areas of science studies, and some work in science education, on a shift between seeing science as about the discovery of how nature is, to being about constructing representations that are necessarily human inventions. The idea that human beings, with their particular mental capacities and apparatus, are able to adequately understand the world (and the sometimes co-existing scientistic notion that if we do enough science we will one day understand everything) were sensible assumptions for early modern scientists who adopted a natural theology perspective of "reading the book of nature", as their religious worldview led them to expect that God wanted people to make sense of His creation (Yeo, 1979). Even if some scientists still adopt such commitments privately today, such ideas are no longer admissible as part of scientific argumentation itself, and for many scientists an implicit commitment to the universe being comprehendible seems little more than an act of secular faith. Indeed in recent times the scientists seeking to persuade the public that science is a kind of epistemological panacea, have tended to be those most critical of religious beliefs (Cray, Dawkins, & Collins, 2006).

Yet analysis of science-in-the-making demonstrates just how indirect and reliant on boot-strapping the constructions of some scientific products are—the "discovery" of sub-atomic particles in physics being one high profile example (Knorr Cetina, 1999). It has been recognised that the work of the science teacher is parallel to this, with teachers using language and gestures and models and so forth as rhetorical tools to help learners construct the objects of science for themselves in their own imaginations (Lemke, 1990; Ogborn, Kress, Martins, & McGillicuddy, 1996).

The Drive for Enquiry-Based Science Teaching

A third important consideration is the international movement towards what has been described as enquiry-based (or inquiry-based) science education rather than simply learning science as a "rhetoric of conclusions" (Schwab, 1962). Science as an activity is about enquiry into the natural world, to develop further understanding through the interplay between, on the one hand, empirical observations and investigations and, on the other, the development of theory. An authentic science education therefore needs to give learners the experience of enquiry. Of course professional scientific enquiry relies upon scientists having an extensive specialised knowledge base, access to state-of-the-art apparatus and well- equipped laboratories, and being able to engage with scientific problems continuously over extended periods of weeks and months. School science cannot draw upon a comparable resource base, and it was recognised well over a century ago that transposing scientific enquiry into schools could not simply mean expecting students to undertake self-directed unguided enquiry (Jenkins, 1979).

Despite this, there has been a considerably influential movement arguing for teaching science as enquiry (Lawson, 2010). This can be considered as part of the broader impetus to shift the emphasis of science teaching away from teaching primarily about some of the findings of science ("content") to including more emphasis on the nature of science ("process") (Clough & Olson, 2008; Hodson, 2009; Lederman & Lederman, 2014; Matthews, 1994). Indeed influence from the "nature of science" lobby has allowed a richer understanding of scientific enquiry (as being much more nuanced than simply testing hypotheses through controlled experiments) to evolve within science education (Lederman & Lederman, 2012; Osborne, 2014).

Objections to Constructivist Science Education

Teaching through enquiry has also been a focus of the debates within the wider educational community that has seen what are viewed as constructivist approaches to pedagogy heavily criticised in some quarters (Berube, 2008; Taber, 2010a; Tobias & Duffy, 2009). This is a complex debate, but one key problem is how constructivist teaching is understood by some of its critics—especially when it is considered that constructivism, child-centred instruction, enquiry-based teaching, active learning, and progressive pedagogy, can be clumped together as synonymous (Kirschner, Sweller, & Clark, 2006). Critics have argued that constructivist science teaching is minimally guided and assumes students can rediscover major scientific ideas for themselves, whereas teaching will only be effective when there is direct instruction of difficult, abstract ideas. Some have even argued that enquiry teaching is favoured in some school systems because the teacher does not need any specialist scientific knowledge as they are teaching learners to find things out for themselves (Cromer, 1997). These criticisms ignore how a main driver for the constructivist movement in science education was the recognition that much minimally guided enquiry work would not be effective as students would develop their own alternative conceptions (Driver, 1983), which once formed were likely to be reinforced by (necessarily "theory laden") observations (Nickerson, 1998).

In one important sense, constructivist thinking *does* suggest that every learner has to rediscover every taught idea for themselves—no matter how directly they are instructed. But constructivist pedagogy is certainly not about open-ended enquiry with minimal guidance from the teacher. Constructivist pedagogy requires a dialogic approach that engages students' own ideas, and explores them critically and in relation to evidence, as a phase in a multifaceted process of presenting the case for why canonical scientific ideas have been developed and adopted (Mortimer & Scott, 2003). An authentic constructivist science education does not require that learners abandon their existing ideas and convert to believe scientific ideas, as science offers theoretical accounts to support understanding and is not about belief, but rather that students become convinced that scientific ideas represent useful and sensible ways of thinking about the natural world (Taber, 2017). Constructivist teaching requires learners to engage in actively thinking about things for themselves, but always supported by suitable scaffolding so that the intellectual challenge of understanding abstract scientific accounts is manageable. Constructivist ideas, when taken in the round (Scott, 1998), inform an optimally guided form of instruction (Taber, 2011a). A more detailed discussion of the criticisms of constructivist thought within science education can be found elsewhere (see Chapter 5 in Taber, 2009).

The English Context

The context of England [2] is of particular interest because the government has adopted educational policy that explicitly accepts some key constructivist ideas—as in some other countries (Bell, Jones, & Car, 1995)—yet this has happened within a wider policy context that severely undermines substantive attempts to adopt research-based constructivist approaches in the classroom on a regular basis. This presents teachers with a dilemma about how to proceed in planning schemes of work and instruction. This account focuses on the period since a major change in the education system in England that was proposed at the end of the 1980s (DES/WO, 1988) and implemented from the early 1990s. This was the point at which the considerable professional autonomy schools and teachers had enjoyed in matters of curriculum was considerably reduced by the first implementation of a prescribed National Curriculum (NC) that state funded schools were required to follow.

The NC has been modified in various ways since its first introduction, although the originally implemented version of the science curriculum was substantially retained until major revisions in 2007 (Qualifications and

[2] England is one constituent country of the United Kingdom of Great Britain and Northern Ireland (UK). However, there are differences in the education systems in England, Scotland, Wales and Northern Ireland (although the Welsh system is largely closely aligned with that in England). Scotland in particular has major differences compared to the English situation. The present chapter therefore limits its scope to considering the situation in England, and some parts (but not all) of what is discussed here also apply elsewhere in the UK.

Curriculum Authority, 2007a, 2007b). Further substantial revisions have recently been produced (Department for Education, 2014). The chronology of different adjustments to curriculum, and related assessment regimes, is complex and the present account focuses on key themes which have been constant throughout the process:

- that the government specifies the science curriculum for students across ages 5–16;
- that the government controls the formal assessment framework within which schools and examination boards have to work;
- that the government offers copious advice to teachers on how to best organise and carry out classroom teaching.

Where the NC specified the prescribed topics to be taught for each phase of schooling in some detail, the guidance went well beyond this to include curriculum sequencing and pedagogy. At the lower secondary school level ("Key Stage 3", for 11–14 year olds) guidance included a model scheme of work for each topic setting out lessons and possible lesson activities (QCA, 2000), and a "framework" document showing how to build up a coherent course from the different topics (Key Stage 3 National Strategy, 2002a).
Where the curriculum and assessment strands of policy are largely backed by legal force (based on powers vested in the Secretary of State for Education by the UK Parliament), the guidance on pedagogy is, officially, purely advisory. This is however an issue where doublethink may operate: teachers are not *required* to follow non-statutory guidance, which only offers suggestions—yet teachers generally assume they are *expected* to follow the guidance. All schools are subject to regular inspection by the schools inspection service, which publishes reports and grades for individual schools, and an unsatisfactory grading can lead to a school being put into "special measures" where the school management may have to cede control of the school.

As an example, at one point it was suggested in government guidance that all effective lessons have three components—beginning with a starter activity, moving to a main learning activity, and concluding with a plenary session. This three-part lesson was never an officially required lesson structure, but as it was something school inspectors might look for and comment on, it was not unknown for school head teachers to instruct their staff that all lessons must have this structure (Shaw, 2012). Similarly, where research suggests that meaningful learning of complex or counter-intuitive material (like much that is taught in science) is a slow process that may show uneven development over periods of weeks and months, teachers are told that school inspectors would expect to see visible progress in learning during a single observed lesson. Teachers working with the author and colleagues on a curriculum development initiative were very resistant to the idea that any lesson might leave an idea "hanging" for students to reflect on between classes. Although that might sometimes be educationally sensible, it was seen as dangerous in case inspectors visiting a class expected to see a plenary session at the end of the lesson where students could (supposedly) demonstrate clear progression in learning during that session. Teacher colleagues were also very worried about teaching schemes where sequences of similar but incrementally more difficult tasks were used to scaffold learning about difficult concepts—inspectors expected to see learning had a good pace, and teachers would not be comfortable spending extended periods of time on what seemed much the same form of learning activity (as might be indicated in authentic enquiry) in case visited by inspectors.

Government Guidance on Effective Science Teaching

The English Government has been open to being informed by educational thinking in developing its educational policies. During recent decades the government has under a number of initiatives sought to encourage teachers to adopt pedagogy influenced by constructivist thinking and research. Two particular themes are that (a) teaching needs to take into account and respond to students' alternative conceptions and (b) science teaching needs to involve students in learning about scientific enquiry. Both of these features are to be welcome as reflecting international research and scholarship in the field of science education. Moreover, government seems to have been genuine and well-meaning in taking up these principles. However, as will be suggested below, the wider policy context has worked against effective adoption of the kinds of pedagogies research suggests are needed to meet these intentions.

Recommendations for Teaching Informed by Students' Ideas

The body of constructivist research suggests that learning science is a process of knowledge construction that is interpretative, incremental, and so iterative (Taber, 2014). That is, students inevitably make sense of teaching in terms of their existing conceptual resources (given the nature of human cognition), and build up their understanding piecemeal (given the limitations of working memory when handling unfamiliar material), and so are likely to build upon their existing understandings when they can make sense of teaching in these terms. To respond to this, teachers need to be able to perceive the material to be taught from the learner's perspective, and devise learning activities that are designed to channel student thinking from their existing conceptions towards scientific models, and that build up new conceptual understandings through manageable learning quanta. Once students are thinking about a science topic along inappropriate lines they are likely to develop those existing lines of thought, so the teacher needs to work dialogically (Mercer, 1995), seeking feedback on how teaching is being understood, and using this to make adjustments where indicated. This means that schemes of work have to be designed to fit the way students learn, and then teaching itself requires ongoing "online" modifications of the lesson plan during lessons (Taber, 2014).

The government department in England has through its various agencies [3] advised teachers that students commonly develop alternative conceptions about science and has recommended that effective science teaching involves eliciting and where appropriate challenging students' conceptions. This was one aspect highlighted in a short-lived prescriptive national curriculum for initial teacher education (Department for Education and Employment, 1998), and was a major theme of an extensive teacher development initiative (initially known as the "Key Stage 3 National Strategy", where this referred to the 11–14 age group, and later rebranded as the National Strategies) where a considerable amount of teacher development material was produced informing teachers about common student conceptions and suggesting activities for more effective teaching (e.g., Key Stage 3 National Strategy, 2002b).

This material was research-informed, and in some cases quite sophisticated (e.g., Millar, 2003). However, much of the guidance was written as though eliciting students' ideas could be a quick and unproblematic activity (fitting the role of lesson starter perhaps in the ubiquitous three-part lesson), and, similarly, the function of the teacher to challenge, modify, or develop, students' thinking was presented as straight-forward (Taber, 2010b). To adopt a truly constructivist pedagogy requires teachers to develop their teaching of a topic customised for each class (Brock, 2007), taking into account the development of students' thinking at all stages—and also requires having sufficient time to include bespoke demonstrations, thought experiments, and the like, designed to respond to specific ideas elicited from students. However, in practice the sheer amount of content prescribed for teaching in the NC severely limited the time a teacher could commit to any one topic. This undermined the kind of extended engagement with new ideas in a range of contexts, including customised activities to respond to specific student conceptions identified, likely to bring about substantive and long-lasting conceptual change.

Recommendations to Teach About Scientific Enquiry

The original plan to introduce a NC in schools included an "attainment target" (i.e., something which would be formally assessed) relating to the philosophy and history of science (Statutory Instrument, 1989). That this did not materialise was less a principled change of direction than a response to the reception of the original draft NC by the teaching profession. The initial plans for a NC prescription in one teaching subject (science) that would require all pupils to be formally assessed across about 20 (21 or 17 in different drafts) distinct assessment areas was recognised by those who would have to implement it as completely impracticable. The result was a statutory curriculum with four attainment targets, of which Sc1 was

[3] A characteristic of government in the UK in recent decades has been the establishment of quasi-independent agencies or non-ministerial departments to follow through on government policy, and which are from time-to-time rebranded, abolished, merged, and so on. These have included a Teacher Training Agency which became the Training and Development Agency for Schools, and a Qualification and Curriculum Agency, the Office for Standards in Education, the Office of Qualifications and Examinations Regulation, and a General Teaching Council for England. The latter was supposed to be a professional body for teachers, but was both established, and then later wound-up, by government decree.

"Scientific Investigation" (with Sc2–4 being basically biology, chemistry, and physics, although these labels were not used). At the time these changes were planned, it was suggested that teachers would be able to develop practical activities for their classes, drawing from any aspects of the curriculum, to teach and assess students in that aspect of science.

The imposition of a NC on teachers was also the imposition of a new national assessment regime showing that from the beginning of the process the official policy closely linked curriculum and assessment. A danger in such an approach is that the reasonable notion that "if it is worth teaching, it is worth assessing" can readily become twisted to lead to assessment-led teaching where what gets assessed is what it is easy to assess reliably (and in particular, to quantify), so what gets taught is what is easy to assess, rather than what it is considered important to learn. This has certainly been seen in the English NC era. The NC required all students to be assessed in science before leaving primary school with the expectation that on starting secondary education at 11 years of age, students would arrive with an assigned "NC level" which should inform such matters as student grouping in secondary school. Further formal assessments would be carried out for all 14 year olds.

This is in a context where previously students had been not been subject to formal national assessments before external examinations at age 16, with schools selecting from a range of examination boards, each independent of government (generally having been set up by Universities), and offering their own syllabi. This was a system where there was flexibility in the subjects offered so it was possible for schools to choose courses leading to examinations from a wide range of options such as in general or integrated science; the core science subjects of biology, chemistry, and physics; and a range of other options such as rural studies, astronomy, geology, or automotive engineering science. Even under a single subject heading, such as biology, examination boards might offer examination specifications with different emphases or options. This allowed schools to reflect local circumstances and to meet the needs of diverse groups of students. As syllabi could vary considerably across different examination boards, it was possible for a teacher to choose a syllabus that reflected their interests or strengths within a subject. Some syllabi were actually designed by examination boards in partnership with, and to meet the needs of, particular groups of schools.

Under the new NC regime, however, all students had to follow the common curriculum and be assessed across Sc1–4 according to the prescribed criteria. (It was possible for schools to offer separate courses of biology, chemistry, and physics, but students had to then take all three subjects which collectively had to cover, and extend beyond, the NC "science" curriculum.) The number of English examination boards was limited to three (requiring mergers of existing boards), and each was only allowed to offer two alternative examination specifications per subject. At the end of secondary school, when students were 16, the teachers would be responsible for assessing students' skills in Sc1, while the students would take formally invigilated, externally marked, examinations to test their knowledge and understanding in Sc2–4.

The decision to use teacher-assessment of students' attainment in scientific investigation was in principle a progressive move. Investigative skills could be tested during authentic school laboratory work rather than in the more artificial context of formal examinations. Teachers were also encouraged to be creative and explore different contexts to assess students, and it was even acceptable to repeat the assessment process at different times to allow students to develop their skills and achieve at higher levels.

However, although teachers were to be entrusted with making the assessments, which counted as 20% of the final science marks in the high stakes school leaving examinations, they were not trusted to do so without due scrutiny. Teachers had to send students' reports of their practical work, annotated to show how marks were awarded according to the set criteria, as evidence of the investigative work undertaken, for moderation by staff employed by the examination boards. Where the moderators could not find sufficient evidence to unambiguously support marks awarded, these were reduced. This undermined the logic of asking teachers to assess during normal school practical work across a wide range of investigative activities. Very quickly teachers came to use fairly standard activities that had been proven to produce the evidence required. Moreover, rather than sampling appropriate activity from diverse laboratory work, there was a tendency to prioritise practical work suitable for the kinds of assessment needed. In some cases this had repercussions for lower secondary teaching, as practical work during the early years of secondary science sometimes came to be seen as preparation for the particular kinds of "investigations" found suitable for scoring and demonstrating evidence of good marks later in the school.

There was a tendency for prioritising controlled experiments where variables could be measured, and plotted on a line graph—as this most readily fitted the assessment criteria—so distorting students' experience of the range of forms of scientific enquiry. More often than not, these investigations "enquired" into science that students should already know: how the radius of a conductor affected current flow; how concentration of acid influenced its rate of reaction with a carbonate; how the distance of a lamp from some pondweed influenced the rate at which it released bubbles of gas. Moreover, teachers found that higher marks were achieved if they assessed different assessment criteria in different activities—when students were asked at any one time to focus on planning an investigation, or collecting data, or analysing data, or evaluating a procedure. That is, students were commonly taught and assessed in scientific enquiry by disjointed activities such as analysing data they had not collected.

An innovation which had seemed to have potential to support enquiry work in schools had in effect largely curtailed any meaningful enquiry in school laboratories (Taber, 2008). Again teachers were encouraged to adopt a form of doublethink, knowing that they were free to (indeed, supposedly, encouraged to) carry out and assess whatever practical work they thought was educationally valuable, but also knowing that they were judged by how well students achieved in relation to criteria best met by undertaking discrete activities in familiar contexts (that did not require genuine enquiry) within a specific narrow model of experimental method that they had been coached in applying. Official policy had, counter to intention, effectively curtailed enquiry teaching in many schools. Recognising problems, the government changed Sc1 from just being about scientific investigations to being more widely about scientific enquiry. Initiatives were supported to develop teaching about the relationship between ideas and evidence in secondary school science (Braund, Erduran, Simon, Taber, & Tweats, 2004). However, there was much criticism of the students' experience of the science curriculum and the impression of science it offered (Cerini, Murray, & Reiss, 2003; Osborne & Collins, 2000)—including the excessive carousel of topics to be taught and the lack of opportunities to make science appear more relevant to many learners.

The government did take into account these criticisms and the advice of science education experts (Millar & Osborne, 1998), and this led to a complete overhaul of the school science curriculum. The outcome was a prescribed NC for science with much reduced compulsory content and structured so as to balance consideration of specific science topics with broader aims relating to the nature of science processes

(Qualifications and Curriculum Authority, 2007a, 2007b). Ongoing criticism of the over-prescriptive, one-size-fits-all, NC had after a decade and a half led to a completely re-thought approach to the science curriculum which offered considerable more flexibility and room to focus much more on enquiry and other aspects of the nature of science. This included the adoption by one of the examination boards of a novel "specification" (the term which had replaced "syllabus" in the NC era) which offered opportunities for much more context-based teaching, with the intention to regularly change the specific topics included to reflect current issues of socio-scientific relevance. Including exploration of socio-scientific issues in school science (Sadler, 2011) was seen as important to prepare young people for full citizenship in modern societies where policy discourse incorporates scientific arguments about environmental issues, medical technology, and so forth. There is also a strong case that socio-scientific issues offer particular contexts to support cognitive development and challenge gifted learners of science (Taber, 2016).

Responses to a Progressive Curriculum

The reaction to the 2007 version of the NC for science was interesting. Some teachers did not seem to believe it was to be taken seriously. Some teaching colleagues suggested that although many of the topics previously prescribed were no longer actually mentioned in the new curriculum, they would surely still be expected to teach them all; after all, they had been part of the recommended framework and scheme of work. Teachers expected that parents, head teachers, and inspectors would still expect topics previously prescribed to be taught. Many younger teachers had only worked under the NC regime and seemed to readily adopt the doublethink that although they knew that the 2007 NC specified what must now be taught, they were really nonetheless still expected to teach what was no longer specified.

The new examination courses designed for the more liberal curriculum were subject to extensive criticism in the press and other public media. This is unusual in England where each year's external examinations are subject to scrutiny—errors in question papers are widely reported, and most years the newspapers run reports that higher pass rates or lower pass rates must mean educational standards are dropping [4] - but the curriculum content is usually largely ignored. Commentators who normally took little interest in school science and had no expertise in education were quick to criticise the idea of science lessons that might include discussion of socio-scientific issues as being only suitable for the public house (i.e., a place for informal chat over drinks). In particular the senior minister, the Secretary of State for Education, decided that science teaching that explored how diverse values, interests, and perspectives, impinged upon the application and social uptake of science (i.e., classroom activity requiring much more than just understanding the science concepts) was not rigorous enough (Beck, 2012), and despite offering rhetoric of "empowering teachers" and wanting "a National Curriculum that acts as a foundation of core knowledge – not a detailed blueprint for lesson plans" (Gove, 2011), demanded a return to science teaching that involved learning of a great deal of traditional science content. That is, a return to an approach out of keeping with international trends, and which had stymied the teaching of authentic enquiry skills, as well as teacher creativity, and—as far as many school students were concerned —personal relevance. The result was a further revision of the NC and a return to a content-packed list of prescribed topics (Department for Education, 2014). The teachers adopting doublethink were proved correct—they were still expected to teach the relentless carousel of science topics whatever the more stripped back NC documents may have officially prescribed. The opportunity for teachers to have more freedom and follow their professional judgement had, in the opinion of powerful reactionary voices, led to too many making the wrong choices.

Coda

At the time the author of this chapter entered science teaching, school teachers were trusted to make substantive decisions about curriculum and were left to take professional responsibility for determining pedagogy. Over two decades into the NC era teachers now expect to have curriculum prescribed, and to be accountable not only for examination results in high stake tests, but also for being seen to follow "approved" pedagogy in the classroom.

Teachers have also become widely adept at taking up and implementing successive waves of government-sponsored initiatives (on literacy in the classroom, on the use of educational technology, on providing for the gifted, etc.) knowing that any strong interest and funding support from the government will normally be

[4] National examinations in the UK adopt an odd mix of criteria referencing (with grade boundaries expected to reflect published grade descriptions) and norm referencing (with some critical grade boundaries shifted to better match distributions of grades awarded in previous years). The popular press commonly interpret increases in pass rates as a sign of decreased rigour in the examination system with questions getting easier or more generous marking; they have also interpreted decreases in pass rate as a sign that teaching quality is falling and schools are not as good as they used to be.

short-lived and that scrutiny will often be at a surface level. It is in this context that science teachers in England were asked to adopt constructivist inspired teaching techniques, and to teach and assess enquiry in the form of "scientific investigations". The common response was in many regards the sensible one: to incorporate these expectations within their work in a way that was clearly obvious (to any observing members of the school leadership team or any visiting inspector) without fundamentally changing their professional practice. Eliciting students' ideas could make a suitable starter in a three-part lesson, and investigations could be developed to allow students to convert routine practical exercises into line graphs, based on averages of repeated measurements to ensure reliability, and preferably including a circled outlying point to demonstrate that a questionable datum had been noticed, and giving a credit-worthy opportunity to suggest a standard improvement to the method.

It was suggested earlier that there is a sense of Orwellian doublethink in operation here. Teachers have to believe in constructivist educational principles, while believing that they can teach effectively in a context which does not support substantive constructivist teaching. Teachers have to believe that enquiry is at the heart of science, while also believing that good science teaching means covering copious content and offering algorithmic practical work that never moves away from what is clearly already known (so that outcomes can be expected and fitted to the appropriate assessment formalism). Many science teachers in England can show considerable ingenuity in producing lessons offering the expected indicators of constructivist pedagogy and enquiry learning while meeting all the myriad other expectations of the content-heavy curriculum, nominal enrichment for diverse groups, recommended pedagogical devices, and, in particular, teaching targeted on what they know is likely to be included in high stakes examinations. Just what these skilful, creative, science teachers could achieve if ever they were allowed to take full professional responsibility by prioritising their own aims for their students' learning, and then teaching accordingly, is sadly, for the foreseeable future at least, likely to remain a matter for speculation.

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