How Science Works

The impact of a curriculum change on classroom practice

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Abstract

Background: In 2006 the UK National Curriculum for Key Stage 4 (KS4) was changed and increased emphasis was placed on *How Science Works* (HSW). KS3 and KS5 (Subject Criteria) followed suit around 2006. HSW encompasses those strands of curriculum which cannot be said to belong to any of the sciences in particular, such as History and Philosophy of Science (HPS), and investigative and socio-scientific aspects.
Aim: This study aims to investigate the impact the curriculum change had on the classroom practice of UK secondary school science teachers, the influences they feel they have been subjected to surrounding the curriculum change, and their opinions of the curriculum change itself. The study is further informed by related practitioners' reflections on the effects they may have had on teachers and their practice.
Sample: Twenty-five secondary school science teachers from eleven different schools of five different school types participated in the study, as well as six textbook developers, two examiners and three science education consultants. Participants comprised a mix of males and females, from various science subject backgrounds, who had all been secondary school science teachers in the UK for varying lengths of time.
Method: Participants engaged in a semi-structured interview of up to one hour about their current practice regarding HSW, as well as the changes they made specifically for HSW and any related feelings and opinions. Where feasible, teachers were observed in a lesson in which they had planned to address at least one aspect of HSW.
Results: Participants had varied opinions on whether change had been necessary, based on recognition of HSW in earlier versions, but also recognition of the importance of HSW per se. As a group, the teachers displayed a spectrum of readiness to change, with most teachers either pioneering, embracing or following the change, and very few displaying signs of reluctance or subversion. Practice had changed under a variety of influences, of which the new curriculum was the main of the so-called 'external agents'. Factors internal to school as well as personal agents were also brought forward.
Conclusion: The study investigates a broader sample of teachers than has been studied before in the context of HSW. Although varying in their interpretation of the curriculum change and their eagerness to respond to it, the majority of teachers had made some changes, by expanding their repertoire of teaching activities, most notably in dealing with HPS and socio-scientific aspects of HSW, often at least partly in response to assessment requirements in those areas.

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Acknowledgements

If anybody would have said around five years ago that I would be embarking on another PhD project, I would have probably accused them of having a screw loose. In the event, the one with the loose screws was me, but I have enjoyed the experience immensely. The first PhD was certainly not an immunisation against the pains and problems a PhD period inevitably causes – it involved as much blood, sweat and tears this time around as it did the first time.

After a brief stint as a secondary school science teacher in the academic year 2008/2009 I was ready to get my teeth into something new. What better than to investigate how science teachers work, and how they deal with the influences of a new curriculum which had recently been introduced? It was fresh in people's minds, and seen as important, if the prevalence of requests for 'a *How Science Works* lesson' as part of job interviews was anything to go by.

I would like to express my thanks to all those people who have played a part in getting me to where I am now.

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For my children

Author’s declaration

I, Maria Gertrudis Wilhelmina Turkenburg-van Diepen, declare that I am the sole author of this PhD thesis and that no part has been publicly presented anywhere else.

1 Introduction

1.1 Aims and background of the study

1.1.1 General overview

It has long been thought that learning science involves learning about the methods and processes of scientific inquiry, the history and philosophy of science, and socio-scientific implications, as well as the established content knowledge of science (Bell, Abd-El-Khalick, Lederman, McComas, & Matthews, 2001; DeBoer, 1991; Dewey, 1910 (reprinted 1995); Lederman, 2007; Millar, 1989, 1996). Despite this long history of considering what constitutes an appropriate science education, the investigative strand of the National Curriculum (NC) for Science has gone by a number of different names, and the other aspects have similarly appeared in a variety of incarnations. In 2006, a new phrase was introduced as the heading for the investigative and epistemological strands along with those other parts of the NC which are not specific to one type of science in particular, but which are all important for the teaching and learning of all science. This phrase was *How Science Works* (HSW). The historical background to this curriculum development will be presented in section 1.1.2.

HSW has therefore become a prominent curriculum element in the National Curriculum for science in secondary schools in England and Wales. It comprises the History and Philosophy of Science (HPS, further shortened to H), Scientific Inquiry (Investigation, further shortened to I), Socio-scientific aspects (shortened to S), and Communication (shortened to C). These four subsections are most easily recognisable in the NC for Key Stage 4 (DfES & QCA, 2004).

Giere (1991) built up a picture of science, or scientific understanding (see Figure 1.1). It shows a hypothetico-deductive view of the scientific enterprise. Scientists start with “a question about some aspect of the natural world”. Society (S), contained in that world, may put constraints and restraints on what scientists do, but may benefit from scientists’ output. The next step of the enterprise is to perform investigations (I), through observation or experimentation, to obtain data. At the same time, through creative and philosophical means (depicted by H across the top of the figure), scientists propose explanations for natural phenomena on the basis of all information that is available to them. Through reasoning and calculation, processes with aspects of philosophy/communication/inquiry (reminiscent of sections H, I and C in the science curriculum), predictions are made about other phenomena which ought to be explained by the theories as they are proposed. These predictions are checked for agreement with current data, and more data are obtained as needed (process H,I at the bottom of the figure). As more data become available, explanations become more sophisticated, and new predictions on the basis of the explanations are confirmed, "our confidence in the explanation increases"; or, conversely, our confidence decreases if more data become available which cannot be explained through current theories.

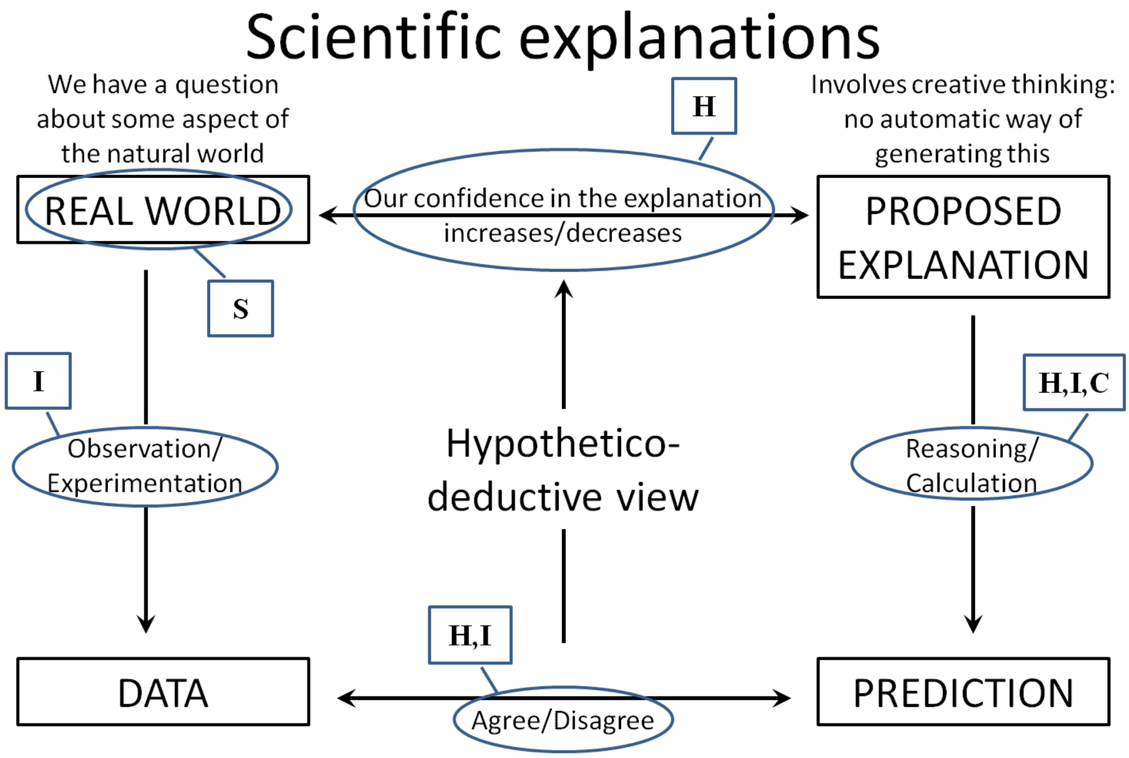

Figure 1.1. Giere's hypthetico-deductive model of scientific explanations (adapted from Giere (1991, p. 32))

As shown, Giere's hypothetico-deductive model is a useful representation of HSW as it appears in the NC for science in secondary schools in England and Wales.

HSW was a new initiative, rooted in the desire to provide a suitable science education both for 'citizens' and for 'future scientists'. The need for this was highlighted through a series of seminars consulting experts in science education towards the end of the last century, culminating in the report *Beyond 2000* (Millar & Osborne, 1998). The recommendations from the report led to the development of a new type of suite of GCSE courses, Twenty-First Century Science (TFCS), which became the model for other GCSE courses. The model initially comprised Core Science, for everybody, and Additional Science, for all but the very weakest students. It was then expanded with Applied Science courses for vocationally interested pupils, and separate science courses for the most able. At the time of the increased emphasis on HSW in the NC, this was the model all GCSE specifications conformed to.

As with any significant change, the new curriculum warranted study to get an overview of the effect of the curriculum policy change on the ground, from a variety of teachers which represent the whole of the secondary school teaching community. This includes gauging users' views about the specific new policy and its implementation, to improve our understanding of the processes of change in science education and education in general. Fullan (2007) argued that if teachers are not engaging with the intended change, it is unlikely that any significant change will actually happen. Research into users' responses to a policy-led change also informs new ideas for next steps in the development, for policy makers and for new research. In addition, it provides food for thought for those people who, by their own professional efforts in the realms of textbooks and assessment for example, have a direct influence on teachers' practice.

Teachers are likely to have responded to the curriculum change in some way, to integrate new aspects into their teaching alongside what they were already doing. To some extent, they will have followed their own interests, within the boundaries of their professionalism. These effects will be studied here, while trying to discern patterns in teachers' practice regarding HSW, as well as their eagerness to adopt HSW as part of their teaching, and their thinking around it. The change in which HSW was given more prominence in the science curriculum has not been studied in much detail so far. There is a limited literature, mainly written by academics rather than teachers, discussing what HSW might be and how it might be taught. This will be presented in detail in chapter 2, along with the international literature about the Nature of Science (NoS) with which it has much in common.

The main aim of this study is to come to an understanding of whether and how teachers' practice has changed as a result of a curriculum change, and what their perceptions are of the change and the implications of it. The study therefore has a number of objectives (see research questions, section 3.2) and is investigating an area of interest which has been only sparsely explored. It has a clear link with the theories of educational change, which will be discussed in chapter 2.

1.1.2 Historical background of HSW in the National Curriculum and A-level Subject Criteria (NCASC)

After decades of curriculum development projects, in the 1980s the Secondary Science Curriculum Review scrutinised secondary school science for all. This was a joint project of government and the Association for Science Education, resulting in proposals for a ‘minimum entitlement’ of science learning for every pupil, appropriate to their needs for everyday life and work, a new ‘double science’ course and the belief that curriculum reform and development should be left to the teachers and their professionalism. Despite this, the government of the day had no intention to leave curriculum reform to the teachers. The Education Reform Act of 1988 paved the way for the first NC for science (1989) for all pupils aged 5-16 in compulsory education in maintained schools, along with some other major changes such as national testing for 7-, 11- and 14-year-olds, and a new inspection regime through Ofsted (Office for Standards in Education, Children’s Services and Skills).

The first NC for science contained 17 Attainment Targets, one of which was ‘The nature of science’. This section aimed to give pupils an understanding of how and why scientific ideas develop and are important, that science is not the only way towards understanding, and the implications of the interplay between science and society (DES & The Welsh Office, 1989). Another Attainment Target dealt with ‘Exploration of science’, which meant the investigative side of scientific study, from development of theory through experimentation to communication of ideas.

Over the next decade, through three NC revisions, the content of the investigative section was relatively constant, although named differently each time: ‘Scientific Investigation’ (DES & The Welsh Office, 1991), ‘Experimental and Investigative Science’ (1995), and ‘Scientific inquiry – Investigative skills’ (1999). The section about ‘The nature of science’ suffered a rather different fate. In 1991 the ideas were scattered among the sections describing content knowledge, with no special status at all. In the

1995 version ‘The nature of scientific ideas’ featured as one of the introductory sections of the programme of study to be applied across all areas of teaching, but not to be used in assessment. ‘Systematic enquiry’, ‘Application of science’, ‘Communication’ and ‘Health and safety’ were given similar status.

Following the Dearing Review 1992/1993 (Dearing, 1994) and the new NC of 1995, it was decided there should be no curriculum changes for five years, to establish some stability. Millar (1996) suggested this was the time to carefully think about the purposes and aims of the NC for science, and to develop this into a curriculum which was really suitable for all and to improve scientific literacy for everybody – a goal which had been put forward for some time. A change of government in 1997 gave this some urgency: the Secretary of State asked for a limited review of the NC in readiness for the year 2000, to be followed by a more extensive review in the following five years. Millar had argued that the curriculum should be built around ‘big ideas’ of science, which must not get lost among the detail. For this to be successful, he proposed the identification of a few key scientific models and theories, a more technological emphasis, case studies of actual scientific work and applications of science, and more extended practical investigations exemplifying the need for empirical evidence (Millar, 1996). The report *Beyond 2000* offered recommendations for the implementation of a new type of curriculum for the future (Millar & Osborne, 1998). While the report was examining the full range of curriculum for science, its aims and recommendations fit with an increased emphasis on learning science for scientific literacy and an understanding of how science works rather than acquiring detailed factual knowledge.

In the 1999 NC a prominent place was given to ‘Ideas and evidence in science’ as the first part of the section ‘Scientific enquiry’, before ‘Investigative skills’. This gave a hint of the renewed effort to place importance on the NoS as part of the NC. Then in 2004, while only key stage 4 (KS4) was revised, came the big change to *How Science Works* (HSW): what had been ‘Scientific enquiry’ in 1999, plus everything else which cannot be caught under the heading of ‘scientific content knowledge’ was put there. The overall aim of the curriculum, and the ways and means of teaching it, did not necessarily change very much, but the role of the parts was reversed, resulting in a very different emphasis. HSW was now prominent, and could, and perhaps should, be taken into account at all times when considering the teaching of the scientific content knowledge.

For 2007 the curriculum for KS3 was revised (2007a), with *How Science Works* as an overarching concept if not under a separate heading in the programme itself. Although post-16 education does not have a national curriculum, the QCA set out subject criteria which all subject specifications have to use as a framework, and which became the responsibility of Ofqual (Office of Qualifications and Examinations Regulation, 2009). In 2006 *How Science Works* was introduced into the subject criteria for science A-level specifications, for teaching from 2007 (QCA, 2006). The 12 statements representing the requirements for the teaching of *How Science Works* for post-16 science are shown in appendix A, alongside those for KS4 and KS3. The KS5 statements map very closely onto the 14 statements in the KS4 NC of 2004.

On January 20, 2011 a review of the National Curriculum for key stages 1-4 was announced (for consultation documents, see DfE (2011a)). Numerous organisations have contributed collective statements, such as the Association for Science Education (2011), the Nuffield Foundation (2011), and the Council for Subject Associations (2011). In the newly proposed curriculum (DfE, 2013) HSW is no longer used, but the individual sentiments of HSW, such as the investigative strand and aspects of NoS and the applications and implications of science, are easily recognisable. As so many people consider HSW to be important, it is likely to continue to feature in some guise, and may well become more prominent again in the future.

1.2 Structure of the thesis

Following this introductory chapter, chapter 2 presents a review of the international and national literature regarding NoS and HSW, considering what these terms are taken to mean, and why and how an understanding of these aspects of science might be taught. It also reviews literature on the impact of policy-driven changes on teacher action and educational practices in general.

Chapter 3 describes research strategy and research techniques. The approach taken to achieve consistent collection of rich data is described, including the lessons learnt during pre-pilot and pilot stages. For reasons that are more fully explored in chapter 3, it was decided to collect data by observation of teachers, and by in-depth interviews. In addition, textbook developers, examiners and consultants were interviewed to further inform an understanding of the influences on teachers about which these related practitioners are experts.

Chapters 4, 5, 6 and 7 present the results from the data obtained from the teachers' interviews. Chapter 4 introduces two frameworks to describe the teachers' responses to change. The first framework exemplifies the teachers' self-reported level of change in practice; the second framework developed from the first when it became clear that within each of the sub groups of teachers the readiness to change varied, resulting in a spectrum. The chapter then describes the teachers' current practice, examining their emphasis on the History and Philosophy of Science, investigative science and socio-scientific aspects of the HSW strand of the curriculum, as well as skills, assessment, and textbooks.

Chapter 5 presents an examination of teachers' reflections about science itself, its place in secondary school education, and the requirements for teaching it.

Chapter 6 presents teachers' reflections on the influences on their practice as they perceive them, examined according to a framework developed by Goodson (2003). Influences are grouped according to whether they are personal to the teacher, internal to the teacher's school, or external to the school. The HSW strand of the curriculum is part of governmental policy, and therefore an external influence. It will be examined in the context of all other influences as brought forth by the teachers in the study.

Chapter 7 presents teachers' reflections on the emphasis on HSW in the curriculum. Responses to the emphasis can be classified as positive or negative, although at times a response may either be neutral in itself, or contain both positive and negative elements and may therefore be considered neutral on balance. A variety of these responses are examined.

Chapter 8 presents the results from the data obtained from the related practitioners – textbook developers, examiners and consultants.

Chapter 9 reviews the main conclusions from the study, discussing the research questions in turn; describes more recent curriculum development, which some of the teachers and related practitioners referred to in our interviews; presents a critique of the study, outlining the strengths and weaknesses of the strategy and techniques which were employed; discusses some implications from the study for teachers, policy makers, examiners and researchers; and, finally, presents some concluding remarks.

The appendices are copies of documents produced for or related to the study. These include: the initial approach to the teacher participants; interview schedules and consent forms; an overview of the observed lessons; and the HSW part of the NCASC for each of the relevant key stages, as well as the Assessment Foci for Assessing Pupils' Progress (APP) at KS3.

2 Literature review

2.1 Introduction

How Science Works (HSW) can be seen as a collective phrase for all of science teaching and learning which cannot be placed under one sub-specialism of science in particular. But there is more to *How Science Works*: it is designed to give an understanding of how we know what we know, and how and why learning science gives us that understanding. It thus provides an opportunity to work towards achieving scientific literacy.

There is much educational research and science teaching to improve scientific literacy, even though the term itself is not well-defined. One definition is "the knowledge and understanding of scientific concepts and processes required for personal decision-making, participation in civic and cultural affairs, and economic productivity" (National Research Council, 1996). In order to achieve this, we must teach what is variably called "ideas-about-science" (Bartholomew, Osborne, & Ratcliffe, 2004; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003), the Nature of Science (Lederman, 2007; McComas, 1998; Solomon, 1991), or *How Science Works* (Toplis, 2011; Williams, 2011). It is acknowledged in the international literature that this is a complicated prospect, which Lederman and Zeidler (1987) put as follows: "Improving the scientific literacy of the public is one of the most compelling challenges facing science educators" (p. 721). An emphasis on *How Science Works* in the science curriculum may help to address this.

In order to study the impact on science teachers of the most recent curriculum change in England, in which *How Science Works* was introduced with a major emphasis, a background knowledge of the literature is required, in particular the international research literature concerning Nature of Science (see section 2.2), followed by a forage in the (educational) change literature (see section 2.3), leading to that national professional literature surrounding the change itself in which *How Science Works* is the main feature (see section 2.4). A review of the professional literature is considered important in order to gain insight in the issues raised in the literature to which teachers themselves have easy access through their professional associations. Based on those three bodies of literature, it may be possible to answer some questions about the impact it has had on science teachers, on their actions in the classroom, and on their thinking about this curriculum change.

2.2 Teaching (the) Nature of science

2.2.1 Introduction

Much has been written over recent decades about the nature of science, and what essence(s) of it might be taught to secondary school pupils. Many researchers have attempted to extract the essence of science and build a picture of the desirability and possibility of teaching Nature of Science, as well as how this may be accomplished in a normal classroom setting.

The phrase ‘the nature of science’ will be used here in two rather different ways. When it is an integral part of the sentence and the thought expressed, it tends to need a definite article, and there is no need to highlight it in any way – it simply describes a natural entity of language and thought. Alternatively, as in the second sentence of the paragraph above, it represents a specific part of science, science teaching and science curriculum. In this sense, it warrants special treatment to highlight its position. This will be done by capitalising ‘Nature’ and ‘Science’, and by not including an article, hence the inclusion of parentheses in the title. In this way, the abbreviation ‘NoS’ without an article also seems more logical. A similar treatment is given to the use of the phrase ‘how science works’, which will be used without any highlighting where it represents a part of natural language, whereas it will be capitalised and italicised (*How Science Works*), and abbreviated ‘HSW’ when referring to features of the National Curriculum (NC) for science.

The following is a review of the recent international literature about the nature of science and the teaching of it, which has been discussed for around a century (Lederman, Abd-El-Khalick, & Bell, 2001). Teachers’ views and understanding of the nature of science also came under the lens of researchers around 1960 (Lederman, 1992) and will be discussed here.

2.2.2 Nature of Science – what is it?

Scientific method, Nature of Science and *How Science Works* are terms which hint at recognisable or agreed entities of knowledge or activity, e.g. a sequence of steps which might make a 'method'. Unfortunately, the only agreement there seems to be about these terms is that there is no agreement about such entities, or rather that there is no single scientific method, and there is no easy, concise or even comprehensive way to describe the nature of science or how science works. Or, as Donnelly (2001) described:

> "The phrase 'the nature of science', unless carefully qualified, suggests that science can be characterized in some unitary and integrated way. That putative characterization can take the form of a set of intellectual and laboratory procedures, adding up to a 'method'." (p. 181)

The nature of science encompasses aspects of history, philosophy, sociology and psychology, in order to come to a description of what science is and how it works (McComas, Clough, & Almazroa, 1998). Over time, natural philosophy or the philosophy of science has gone from naturalistic explanations for observations through logical reasoning and deductive inference in the times of the ancient Greeks, then *via* inductivism with Bacon (16th century) to empiricism with Hume (18th century). At the beginning of the 20th century came logical positivism, which was overtaken by Popper's efforts of deductive falsificationism. Popper claimed that experimentation and observation can be used to *test* scientific theories but they were not necessarily enough to *produce* them. And his ideas about change in scientific knowledge were of an evolutionary nature – gradual change and development. Popper's ideas were widely accepted to define the boundaries between science and non-science, only to be challenged by Kuhn who introduced the idea of paradigms and that scientific progress occurs through revolutions when the framework of the paradigm can no longer be upheld. Between such revolutions 'normal science' is said to take place. It is this 'normal science' which we might want to describe the nature of, for use in secondary school science teaching.

As Lederman and his co-workers (2002) put it: "Typically, NOS [sic] refers to the epistemology and sociology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development" (p. 498). Lederman's definition has developed over time. Thinking about the nature of science is clearly under continuous development. The implications for school science are multiple and varied, not least that teaching about it will always be behind the times.

2.2.3 Nature of Science – why should it be taught?

Learning about the nature of science seems closely linked to developing scientific literacy, although that is a similarly loosely defined concept. Although a satisfactory definition remains elusive, many persuasive arguments are put forward for the inclusion of the teaching of NoS in science curricula across the globe.

Smith and Scharmann (1999), while attempting to find a description of Nature of Science which may be usable for secondary science teachers in their classrooms, started from a consideration of why an understanding of the nature of science may be worthwhile for secondary school pupils:

> "In our opinion the most important reason students should understand the nature of science is that this understanding is crucial to responsible personal decisionmaking [sic] and effective local and global citizenship." (p. 495)

They emphasized the importance of *understanding*, and that this must not be equated with learning to accept or reject one or other view of science. They also reiterated that around the globe one of the important roles of science education is seen to be the achievement of scientific literacy in general and the understanding of the nature of science in particular.

The question 'why teach NoS?' can comfortably be discussed alongside 'why teach science?' and scientific literacy, as the latter is regularly quoted as the main goal of science education in general, and understanding the nature of science is a major part of this discussion (DeBoer, 2000; Jenkins, 1990). DeBoer equated scientific literacy with the public understanding of science. Jenkins did not do so explicitly, but reviewed literature to make a case for scientific literacy by referring to an important paper about the benefits of the public understanding of science (Thomas & Durant, 1987). The authors of that paper proposed nine arguments for the promotion of the public understanding of science, ranging from benefits to the individual and society as a whole to benefits to democratic government, national economics, and national power and influence. DeBoer, without reference to Thomas and Durant's efforts, summarised nine goals of science teaching which bear an uncanny resemblance to their nine arguments, although grouped and emphasised differently. DeBoer's nine goals are:

1. Teaching and learning about science as a cultural force in the modern world;
2. Preparation for the world of work;
3. Teaching and learning about science that has direct application to everyday living;
4. Teaching students to be informed citizens;
5. Learning about science as a particular way of examining the natural world;
6. Understanding reports and discussions of science that appear in the popular media;
7. Learning about science for its aesthetic appeal;
8. Preparing citizens who are sympathetic to science;
9. Understanding the nature and importance of technology and the relationship between technology and science.

The achievement of scientific literacy and/or public understanding of science is problematic, if only because a definition of scientific literacy is elusive (or rather there is a "veritable deluge" of them (Roberts, 2007)) and 'public' is a broad and varied term. Shamos (1995) therefore advocated renewed efforts to achieve science *awareness* or *appreciation* rather than scientific understanding, which, in his opinion, is best served by instilling an understanding of the nature of science while using as little science subject content knowledge as possible. There is evidence that there may be another good reason to cut down on teaching science subject content: knowledge of it does not tend to 'stick' after it was learnt for an examination (Durant, Evans, & Thomas, 1989; Fensham, 2000) whereas some researchers express hope that understanding of NoS does stick, e.g. through building metacognitive knowledge in science lessons (Hogan, 2000).

Along the same lines, promoting the enhancement of 'scientific literacy' through a curriculum specifically designed with this aim in mind, Millar and Osborne in their seminal document *Beyond 2000* (1998) gave a reason similar to that used by Smith and Scharmann (1999):

> "[T]he ever-growing importance of scientific issues in our daily lives demands a populace who have sufficient knowledge and understanding to follow science and scientific debates [...]" (p. 1)

They used this in support of their recommendation that "[t]he science curriculum from 5 to 16 should be seen primarily as a course to enhance general 'scientific literacy'" (p. 9). The authors put 'scientific literacy' in inverted commas because of their awareness of the complexity of the concept and the over-emphasis of some of the often quoted purposes of science education. They made it very clear that, in their opinion, an emphasis on the cultural and democratic arguments for an improved understanding of science is justified. On the other hand, they "have given less emphasis to the oft-used argument that science should be taught because scientific knowledge is useful for action" (p. 11). In order to achieve scientific literacy, they advanced the necessity of the teaching of "ideas-about-science" through NoS and scientific inquiry. They put in a warning, however, about over-emphasising the linking of success in scientific inquiry to everyday situations – more often than not a common-sense approach is more than adequate in everyday life and the advantage of a scientific approach would be less than obvious. Indications of success of this curriculum design have been reported by Millar (2006), Hanley, Osborne and Ratcliffe (2008), Ratcliffe and Millar (2009) and Millar (2010).

In response to *Beyond 2000* (Millar & Osborne, 1998), Collins (2000) acknowledged that even if he allowed himself to completely ignore practical issues such as that of pedagogical implementation of any ideas proposed, he could not dispute the inherent worth and the potential success of the project. He emphasised the need for science to be taught to everyone, but to make it equally appropriate for those who will not become scientists by using key ideas which will help them "gain an understanding of the world we live in" (p. 169). These may not always be 'tidy' scientific ideas (Collins gives examples of weather and economic forecasting, and statistical sciences). Collins introduced his thoughts on three contradictory elements, the 'trilemma' of science and science teaching, which sheds light on why he thought science and NoS should be taught:

> "What would be taught ideally is that science liberates from tradition and the 'shackles of received knowledge', yet it can only work within a tradition and

> as received knowledge. This in turn means that *science itself* must be taught as a tradition and as received knowledge." (p. 171)

It is only through teaching and learning NoS that these apparent contradictions can be appreciated by and perhaps resolved for students of secondary school science.

In support of the UK curriculum developments for the beginning of the twenty-first century, a group of researchers sought to establish empirical evidence for a consensus about what kind of "ideas-about-science" might be included in such a curriculum (Osborne et al., 2003). They started from a consideration of the question *why* NoS should be taught, and refer to Collins' trilemma and its apparent contradictions. They felt that science education is for the benefit of the citizen as much as that of future scientists, and can only be successful if NoS is taught explicitly so that an understanding of "[science's] underlying epistemic values, methods, and institutional practices" is gained (Osborne et al., 2003, p. 694).

There are many reasons why an understanding of NoS is essential both for future scientists and for all citizens, and hence why it should be taught at secondary school. The arguments can be summarised under the headings of 'economic', 'utility', 'democratic', 'social' and 'cultural' (Millar, 1996). It is thought that an understanding of the nature of science will lead to scientific literacy, which is generally seen as a desired outcome of secondary school science learning.

2.2.4 Nature of Science – what should be taught?

It is easy to see that, with disagreement about what NoS is, there will also be disagreement about what NoS should be taught. If, however, the psychological development and capability of the students is kept in mind, it seems possible (see below, for example Bartholomew et al. (2004)) to reach some consensus about what might be possible to teach and learn about the nature of science at secondary school.

Alters (1997) argued there is no general agreement between philosophers of science who claim to have a view of the criteria for the nature of science. He suggested that the criteria for NoS as used in science education must therefore be kept under review, and that it would be appropriate to adopt a philosophically pluralistic approach to science teaching. This pluralistic approach, according to Alters, means taking account of, and integrating into teaching, ideas from four main movements in philosophy: *a priorism*, conventionalism, positivism and realism. Alters' study is based on a survey of a statistically representative sample of 210 American philosophers of science; 189 of them responded. The survey started with 15 NoS tenets such as "The methods of science are better characterized by some value-type attributes than by techniques" (tenet 3), "Science has a unique attribute of openness, both of mind and openness of the realm of investigation" (tenet 5) and "Science disciplines differ from one another in what is studied, techniques used, and outcomes sought, but they share a common purpose and philosophy" (tenet 15). The respondents were asked to rate their agreement with these statements through a Likert-type scale (Likert, 1932). They were then invited to add to or delete from the list of 15. When no agreement or even categories of agreement emerged from this exercise, Alters drew his conclusion about lack of agreement among philosophers about what should be included when NoS is studied or taught. He did acknowledge that there seems to be some correlation between aspects of philosophy of science and nature of science within and among philosophers, but that did not lead him to conclude that a general agreement may be reached about whose or what NoS should be taught. In rebuttal, in the same journal, a group of internationally recognised experts on NoS argued that while it is easy to make statements on which philosophers of science disagree, there is much evidence (and use in policy documents) of agreed criteria (Smith, Lederman, Bell, McComas, & Clough, 1997). These, they argued, are of direct use to secondary science teachers, unlike the more esoteric ones used in the Alters study. They wrote: "For example, would one expect much disagreement concerning the tentative NOS [sic] or that science is empirically based?" (p. 1102).

One of the reasons they put forward for rejecting Alters' arguments is that many of the tenets are multi-pronged and can therefore be (dis)agreed with on the basis of totally different reasoning. And the authors were in little doubt that the philosophically pluralistic approach as advocated by Alters is inappropriate for secondary school pupils. They recommended the currently practised approach, following published US standards (American Association for the Advancement of Science, 1993; National Research Council, 1996) and using criteria which are agreed to be relevant to K – 12 instruction. 'K – 12' denotes primary and secondary education in the US, for children aged 4-19.

Picking up on the idea that a pluralistic approach based on competing views as advocated by Alters may be appropriate, Rudolph (2000) set out an argument for building a science curriculum around two distinct cognitive goals recognisable in all sciences: developing reliable theoretical models and reconstructing past natural events. Students should then be encouraged to explore these different goals without searching for an overarching single nature of science. Rudolph emphasised that where some types of science are much more concerned with empirical studies (e.g. physical and chemical sciences), others look for a reconstruction of history because empirical study is impossible or unsuitable (e.g. cosmology, phylogenetic mapping of species, and climate change). In order to teach secondary school pupils, however, he promoted a particularist rather than a universalist approach. Starting from the traditionally separate disciplines of science, a class would discuss methods and activities for each specific type of science separately, without referring to an overall nature of science. He did not discuss whether such an approach may cause a different kind of confusion in pupils: if scientist A's science is unique in the methodology used, does that mean that certain techniques are unsuited for scientist B's science? In 2005, Rudolph highlighted a rather different kind of potential confusion with respect to the teaching of the nature of science. He reported on the worrying conflation of NoS teaching with the teaching of scientific inquiry, and the, to him perhaps even more worrying, use of engineering and technology projects for teaching about the nature of science, rather than activities related to the more abstract, established scientific disciplines. He reached the conclusion that engineering activities have a large role to play in student engagement and public engagement with science, and deserve their place in the curriculum on the proviso that it is made explicit, at least to older students, what the instructional goals are: these activities are not science per se and certainly should not be confused with science as a knowledge-acquisition enterprise (Rudolph, 2005).

In their attempts to *describe* the nature of science as usable for secondary school science teaching, while not getting bogged down with *defining* it first, Smith and Scharmann (1999) produced a set of descriptors of what makes something less or more scientific. They used extensive science education and philosophy of science literature to aid their selection, and advanced that this gives them enough support for their proposal of what Nature of Science may be taught. Their list contains twelve descriptors in two categories:

1. The Objects and Processes of Study
    a. Science is empirical;
    b. Scientific claims are testable/falsifiable;
    c. Scientific tests or observations are repeatable;
    d. Science is tentative/fallible;
    e. Science is self-correcting;
2. Values of Science
    a. Science places a high value on theories that have the largest explanatory power;
    b. Science values predictive power;
    c. Science values fecundity;
    d. Science values open-mindedness;
    e. Science values parsimony;
    f. Scientists demand logical coherence in their explanations;
    g. Scientists value scepticism.

They acknowledged that this list is not definitive, but were prepared to defend, explain or adapt their position when challenged (Scharmann & Smith, 2001). They hoped that their list would help teachers and other interested parties develop their own positions and understanding about the nature of science and allow the development of science teaching resources to achieve the same in secondary school students.

In the UK the National Curriculum for science, and hence the description of what NoS should be taught, has gone through a number of revisions since its inception in 1989 (see section 1.1.2). In 2000 an empirical study was undertaken to derive a core of essential elements of "ideas-about-science" (Osborne et al., 2003). This was phase 1 of a two-phase study, where the second phase was concerned with *how* "ideas-about-science" can be taught effectively, which is discussed separately in section 2.2.5 (Bartholomew et al., 2004). The authors used "ideas-about-science" as a wider concept than what they perceived NoS to be, in that it encompasses "social influences on science and technology, the nature of causal links, risk and risk assessment, and the impact of science and technology on society", as an extension to the "narrower subset of philosophical and epistemic issues about the nature of scientific knowledge" (Bartholomew et al., 2004, p. 656). Special care was taken to avoid some of the criticisms Smith and his colleagues gave Alters in 1997. A group of 23 internationally established and acknowledged experts were consulted on their views. These were experts in a variety of science research, use and communication, not limited to philosophy of science as in the case of Alters. These experts, without ever meeting in person or being made aware of each other's identities, through a process called 'Delphi' (Murry & Hammons, 1995), reached consensus on a set of nine themes, which they deemed essential for teaching about science in secondary schools:

1. Scientific methods and critical testing;
2. Science and certainty;
3. Diversity of scientific thinking;
4. Hypothesis and prediction;
5. Historical development of scientific knowledge;
6. Creativity;
7. Science and questioning;
8. Analysis and interpretation of data;
9. Cooperation and collaboration in the development of scientific knowledge.

These themes, along with one other which did not quite conform to the strict criteria applied to make it to the final set, were compared with the list of several dozen standards statements which McComas and Olson (1998) compiled from international science standards documents. This revealed a high level of consensus: the nine themes match the statements which appeared more often in the standards documents than most or all of the others McComas and Olson identified. This finding strengthened Osborne and co-workers' opinion that a consensus *can* be reached about what can be taught in secondary science, despite Alters' challenge, and that a lack of consensus can no longer be used as an excuse for the lack of teaching of NoS. They acknowledged that their data were not uniquely different from those used by McComas and Olson, although empirical rather than documentary. They did not expand on this, but it is entirely possible that some of the 23 participants in the Delphi study had been involved with the development of some of the standards documents McComas and Olson studied, or at least been aware of them.

Donnelly (2001) was more concerned with a description and analysis of the various versions of the National Curriculum for Science in England and Wales, than a definitive answer to the question of what should be taught in terms of Nature of Science. He saw contradictions between two views of the nature of science as presented in three of the four versions described, namely NCS89, NCS95 and NCS99 (NCS = National Curriculum for Science, numbers representing years; in NCS91 the social/cultural view was all but non-existent). According to one view, pupils were meant to learn about the empirical nature of science, and the virtues of observation, evidence and inference. In another, the nature of science was postulated as ‘tentative’ and under various social and cultural influences. Donnelly (1999) was not convinced that these two views were compatible within one science curriculum. According to Reiss (2005) the apparently contradictory views represented “a contest between Popper and Kuhn” (p. 49), and was a reflection of the different interests, both philosophically and professionally, of the people influencing the curriculum developments. Reiss was cryptic about the reasons for these developments, which he described as ‘battles’ – he suggested “[t]he reasons for this battle need not greatly concern us except in so far as the very existence of the battle indicates the lack of consensus in this area among those responsible for the science National Curriculum” (Reiss, 2005, p. 49). Donnelly was a little more explicit when he discussed the implications of the tension between the empiricist/inductivist/individualist views of NoS on the one hand and the social/cultural view on the other. He saw the incoherent policies, especially around NCS89 and NCS91, as mainly due to “groups and individuals with particular intellectual axes to grind” (Donnelly, 2001, p. 191). Whatever the reasons, the tension had serious implications for science teachers with enough vision to view the National Curriculum for Science as a whole.

When considering specific items for inclusion into a curriculum for the teaching of the nature of science, and specifically scientific inquiry, ‘skills’ and ‘processes’ are often quoted. These terms are problematic in themselves, because of the varied conceptions people have of these generic words. On top of that, the processes which would (either intuitively by anyone with an interest in science, or authoritatively by experts) be assigned to scientific method, such as ‘observation’ or ‘inference’, are not exclusively part of the domain of science but equally part of other academic subjects, common sense and life in general (Millar, 1989). Jenkins went so far as to claim that there was “a case for abandoning all reference in curriculum discussion to the term ‘scientific method’ or to any account that attempts to reduce a creative, flexible and diverse undertaking to a uniform and stepwise exercise in logic” (Jenkins, 2007, p. 275).

It would be sage and prudent not to be over-ambitious about what to teach about the nature of science. It may not make sense to teach about all the controversies about the philosophy of science such as the Science Wars and much of what has gone before, as secondary school pupils may not have the psychological and cognitive maturity to understand so many different points of view for what they are, if they have not even been capable of forming their own point of view. There is, however, some evidence that science textbooks have been very conservative in their treatment of science, sticking close to what perhaps might be called ‘Kuhn’s normal science’ (Niaz, 2010; Van Berkel, De Vos, Verdonk, & Pilot, 2000). There are good reasons to give secondary school pupils some idea about the differences in tentativeness between the process and the product of science. The process of science may be considered rife with controversies and diversity of points of view, whereas the product of science, especially that which is taught at secondary school, is often put forward as clear-cut and authoritative.

As can be seen from the lists, arguments and other descriptions produced by so many knowledgeable people from the science education and philosophy communities over the years and across the globe, unanimity about the nature of science will probably not be reached. On the other hand, there are common features, especially if one takes into consideration what might be achievable in secondary schools. Abd-El-Khalick et al. (1998) put forward what they consider to be widely accepted aspects of NoS suitable for secondary science teaching:

> “[...] scientific knowledge is tentative (subject to change); empirically based (based on and/or derived from observations of the natural world); subjective (theory-laden); partly the product of human inference, imagination, and creativity (involves the invention of explanation); and socially and culturally embedded. Two additional important aspects are the distinction between observations and inferences, and the functions of, and relationships between scientific theories and laws.” (p. 418)

This list was underwritten by Clough (2007) with the proviso that it must not be learnt as a list of tenets, but rather used as a basis for understanding the nature of science.

Strangely, Clough used ‘data’ at the end of his quote, rather than ‘laws’, while ‘laws’ is certainly what Abd-El-Khalick and co-workers wrote.

2.2.5 Nature of Science – how should it be taught?

With so many different views of the nature of science among experts, and the acceptance that teachers will therefore also have differing views, it becomes important to decide how NoS can be taught under those circumstances. The first, and biggest, question is: should it be taught explicitly, or are there ways of learning about the nature of science by simply doing it? Another major point is: if there are so many views and influences, will there be a way of teaching it which will not develop (or disintegrate) into indoctrination? And how do we know whether it is really understood?

Alongside the debates about what the nature of science is, why NoS should be taught and which aspects of it may be suitable for teaching at secondary school, there is disagreement about the need for *explicit* teaching of Nature of Science, as opposed to learning about the nature of science *implicitly* through school laboratory-based practical investigations or through stories from the history of science about significant discoveries and developments, for instance. From a study of 15 trainee teachers from one cohort at a university in the US, Palmquist and Finley (1997) concluded that those trainees’ views of the nature of science could be (and were) influenced by implicit and explicit instruction through teaching methods courses, but that most of the changes occurred through implicit routes. The authors took ‘explicitly taught’ to mean that the instructors on the training course specifically set out to teach a concept related to NoS. ‘Implicitly taught’ meant: either the course instructors or the researchers recognised that the trainees could themselves have seen a relationship between a certain non-NoS concept as it came up in one of the courses, and a concept from the nature of science, although neither the NoS concept nor the relationship was part of the planned course unit. The pre-service teachers were surveyed and interviewed at the start of their training, and changes in their views were investigated after they had engaged with one and then both of the methods courses and associated teaching practices. The methods around which their teacher training course was constructed were based on the theories of conceptual change and cooperative learning which, the investigators suggest, were not known for their direct relationship to the teaching about the nature of science. They concluded that the development of pre-service teachers' views of the nature of science towards a more contemporary (which the authors equate with post-positivist) one may be further enhanced by explicit instruction about the relationship between the nature of learning and the nature of science. Palmquist and Finley's model, on which their analysis was built, had six components: 'role of a scientist', 'general', and scientific 'theory', 'knowledge', 'method' and 'law'. In an article of 'comments and criticism' Bell, Lederman and Abd-El-Khalick (1998) countered that the instruction which trainee teachers in this particular study received, was arguably more explicit and extensive than Palmquist and Finley gave credit for, and this was probably the reason for the change in views that most of them underwent. The authors were not impressed with various aspects of the study and did not believe, supported by the wider literature (see, for instance, a brief review by the same research group (Abd-El-Khalick et al., 1998)), that implicit instruction would ever be sufficient to provide trainee teachers with a solid education about the nature of science. Although the study reported on trainee teachers learning about the nature of science, Bell and his co-workers supported the notion that it is appropriate to extend these conclusions to teaching NoS to secondary school pupils, and argued for explicit instruction.

During the 1960s and 1970s, the period reviewed by Abd-El-Khalick and co-workers (1998) with respect to explicit NoS instruction, 'discovery learning', 'guided discovery' and 'process science' was emphasized. It was assumed that 'doing science' was not only a prerequisite for, but also the pinnacle of, learning and understanding science. However, evidence steadily mounted that simply doing practical-based inquiry was not enough, neither for learning science, nor for understanding the nature of science (see for example Wellington (1981), Solomon (1991), Khishfe & Abd-El-Khalick (2002)). Explicit teaching of NoS might be the only way to achieve adequate understanding of the nature of science by students. In fact, Abd-El-Khalick and Lederman (2000) would add to that that *reflectiveness* is an additional requirement for successful learning about the nature of science, at least for teachers.

Hipkins et al. (2005) reported on a study in New Zealand, in which they found that many teachers ignored NoS as it was not assessed in examinations. Therefore it is not sufficient to argue that explicit *teaching* is required in order for pupils to develop adequate understanding of the nature of science: explicit *examination* is also required in order for teachers to consider teaching about the nature of science in the first place. The intimate link between assessment and teachers' decisions on what and how to teach has been described by various researchers. For instance, Donnelly (2001) remarked, when describing the extensive assessment structure in early versions of the science National Curriculum, that

> "[t]he implication was that, where some element of the curriculum was not included in the attainment targets, it would not be taught. This view, and its corollary (i.e. the view that the assessment dimension could be used to change science teaching in desirable ways) appears to have had considerable currency among participants in the process." (p. 184)

Hipkins and co-workers also raised other worrying issues such as teachers confusing NoS learning with practical work or an understanding of science-in-context or the technological applications of science, while not gaining an understanding of epistemology of science, which surely is a part of NoS. Quoting Bell and co-workers (1995, p. 90), they concluded that "further curriculum development and teacher professional development might be necessary to enable teachers to 'integrate the nature of science and technological contexts, with skills and processes, and scientific knowledge and understanding'" (Hipkins et al., 2005, p. 246). In this context their reference to pedagogical content knowledge of NoS, as proposed by Abd-El-Khalick and Lederman (2000), needs a mention – this will be discussed further in section 2.2.6.

Another aspect to consider about the teaching of the nature of science is the danger of indoctrination. A responsible teacher will need to recognise the historical and philosophical challenges to their subject, and use this understanding accordingly (Matthews, 1998). Matthews charted developments of the historical and philosophical views of science in general and as a school subject, and came to the conclusion that science was no longer seen as simply 'a good thing'. Teachers will have to find a way of teaching which takes account of their understanding of the nature of science in the light of a wider debate. Education, Matthews argued, must not degenerate into indoctrination, so teachers must be wary of promoting their own position while teaching NoS – it is rather more important to allow pupils to develop their own positions and be capable of defending that position with adequate reasoning, through critical and reflective thinking. Matthews contended that recognising other positions on the nature of science, and careful translation of this recognition into classroom practice are limited, though achievable and laudable, aims of NoS education. Smith and Scharmann (1999) had similar views on indoctrination (see section 2.2.3). They argued that we need to give pupils the tools to understand a theory and its supporting evidence, and to question the nature, scope and limitations of science, in order for them to make up their own mind about the scientific content they are learning, where appropriate. They argued this with respect to the theory of evolution, and that "[t]o do otherwise is to open ourselves to accusations of evolutionism, scientism, dogmatism, and indoctrination" (p. 496).

Accepting the growing body of evidence for the need of explicit teaching of nature of science, Bartholomew et al. (2004) set about building a picture of what would be required for the effective teaching of it. Their research was the second phase of a project which started with the Delphi study as discussed in section 2.2.4, which was concerned with *what* "ideas-about-science" should be taught (Osborne et al., 2003), which they then extended to investigate *how* this may be done most effectively. From their study in the UK into teaching about the nature of science and its processes and practices, Bartholomew and co-workers concluded that there are five critical dimensions to a teacher's effective practice, which can be used to analyse the teacher's success in teaching "ideas-about-science". These five dimensions form an excellent basis for identifying teachers' professional development needs, both for trainee and experienced teachers. Understanding of the nature of science is only one of those dimensions, and may not be the most critical of the five. Teachers who are consistently on the 'right' of the five dimensions (see Figure 2.1), have a tendency to be more successful in their teaching of NoS. In addition, Bartholomew and her colleagues were very clear that the integration of NoS teaching with scientific knowledge from the rest of the curriculum is the key to successful learning and understanding of it.

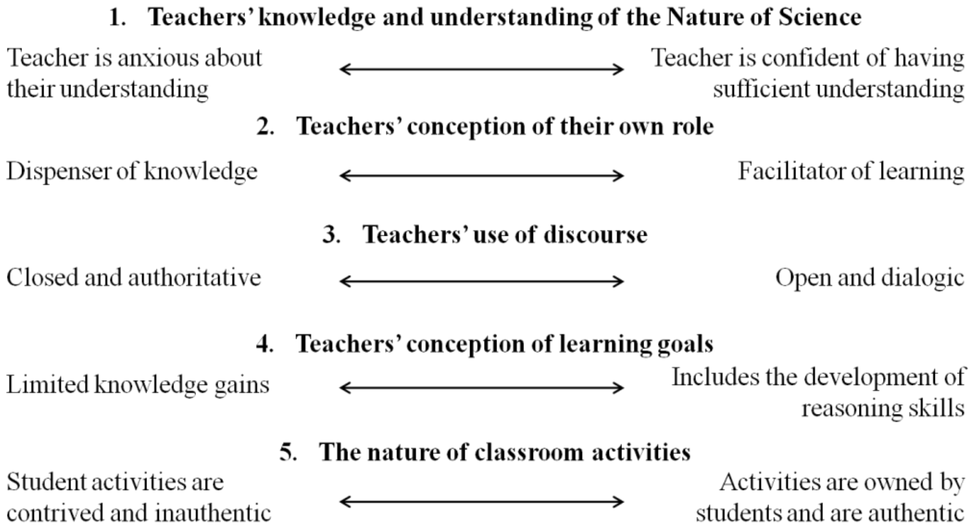

Figure 2.1. The Five Dimensions of Practice (Bartholomew et al., 2004, p. 664)

In summary, there is overwhelming support among educators for the explicit teaching of NoS. There are few who would still argue that it can be learnt implicitly. On top of that, there seems to be a need for explicit examination of understanding of the nature of science, as lack of examination leads to lack of teaching. Teaching about the nature of science must never disintegrate into indoctrination – as philosophers of science are not agreed on what constitutes the nature of science, we cannot expect to instil one view or other of science in pupils. Instead, teachers should attempt to find the best way to teach NoS through the five dimensions of practice: a teacher who is confident in their own understanding of NoS, who employs open and dialogic approaches, facilitating learning and the development of reasoning skills through authentic activities which the pupils can feel ownership of, will be most effective.

2.2.6 Teachers' views and understanding of Nature of Science

There are many studies into teachers' views of the nature of science and the impact these views have on their teaching. As we have seen before, experts are divided as to what constitutes the nature of science, and it may be equally difficult to discover what teachers' views on this subject actually are. The link with teachers' classroom practice and their students' understanding of the nature of science is also unclear.

In order to discover teachers' (and students') views, many tools have been developed. A detailed description of these is beyond the scope of this thesis, but for a comprehensive and up-to-date review and details and difficulties of developing new ones, see Suzuri-Hernandez (2010).

An extensive review of the literature about teachers' (and students') conceptions of the nature of science was produced by Lederman (1992). The research to date had been mainly concerned with assessment and improvement of teachers' and students' conceptions of nature of science, and identification of the relationship between teachers' conceptions and the resulting classroom practices and their students' conceptions. Lederman found that researchers tended to choose to delineate the scope of their research very distinctively: students' conceptions tended to be studied separately from research into the improvement of those conceptions, whereas for teachers the assessment and improvement tended to be studied together. The relationships of teachers' conceptions with their classroom practice and resulting students' conceptions were a fourth line of inquiry. The first two lines of research will be discussed briefly in section 2.2.7, and the fourth in section 2.2.8.

One of the perhaps more surprising conclusions from Lederman's review was that there is no significant relationship between teachers' length of teaching experience and their conceptions of nature of science. Other academic variables, such as degree background or subject specialism, also do not seem to correlate favourably with teachers' understanding of the nature of science. This means it may not be easy to predetermine which kind of intervention may be useful to improve teachers' understanding. A less surprising but all the more disturbing conclusion from the review is that teachers tend to have inadequate conceptions of the nature of science, although this does, of course, depend very much on how 'inadequate' is defined. However, some interventions, especially if they involve historical aspects of the development of scientific knowledge, are successful in improving teachers' understanding (see also section 2.2.8).

Lederman concluded that it is rare for teachers to have consistent contemporary views of the nature of science, and for those to translate to their classroom practices and their students. Dibbs (1982) proposed, as recounted by various others (Hodson, 1993; Koulaidis & Ogborn, 1989; McComas et al., 1998), that teachers could be grouped according to type: inductivist (I-type), verificationist (V-type) and hypothetico-deductivist (H-type). He also assigned a 0-type to teachers with no discernibly consistent views. It is very difficult to disentangle the results of studies of views of the nature of science from the philosophy of science used by the developers of the instruments to measure such views – you tend to get out what you put in (Lederman et al., 2002). Koulaidis and Ogborn (1989) tried very hard to improve on this point compared to Dibbs' study, by distributing their instrument items as equally as possible across the five main views as they saw them at that time: inductivism, hyphothetico-deductivism, contextualism (of either a rationalist or a relativist variety) and relativism. Their criteria for categorisation were very strict, and they found that the vast majority of teachers had to be classified as what they called having 'eclectic views'. If value judgements about the adequacy of teachers' views are left out of the considerations, as advocated by some (Nott & Wellington, 1996), we must conclude that perhaps teachers being consistent is all we can hope for, and even that is few and far between.

Teachers' views of the nature of science are difficult to measure, and, as Koulaidis and Ogborn found, are perhaps best summed up as 'eclectic', in many cases. Assuming that their views have an impact on what goes on in their classrooms, and that they influence their students' views – and those are assumptions that may not be as sensible as they seem (see sections 2.2.7 and 2.2.8) – it seems important that teachers at least understand their own views, and can be confident that their views are appropriate for the teaching of contemporary school science.

2.2.7 Students' views and understanding of Nature of Science

Although students' understanding of the nature of science is one of the main aims of secondary school science teaching, a detailed review of the considerable literature about students' understanding of the nature of science is beyond the scope of this thesis. Lederman's 1992 review forms an excellent basis for further research, while he also raised the issue of the assumption about the existence of a link between teachers' and students' views and understanding being problematic. It goes without saying that a teacher cannot teach what they do not understand, but the assumption that teachers' views recognisably translate to their students' understanding was found to be unwarranted. And it is almost inconceivable that students acquire an appropriate level of understanding if their teachers do not have what some call an adequate level of understanding of the nature of science themselves, but Lederman presented at least one study reporting students gaining better scores than their teachers on the same test (Miller, 1963). For a recent exploration of the literature, and a new instrument to measure secondary school students' views of the nature of science, see Suzuri-Hernandez (2010).

On the whole, a "stubborn persistence of naïve and empiricist views" is found, both in teachers and in students (Hipkins et al., 2005, p. 247). If we feel that students' adequate understanding of the nature of science is one of the aims of school science, we must find a reliable way of translating the view which is accepted as usable for secondary school science (see section 2.2.4) through the levels of the curriculum in a transparent way (see section 2.3). Dibbs (1982), at least, seems to have found a way to secure successful translation at one of the levels: teachers, if they make a conscious effort to be consistent within one view of the nature of science, can translate their views onto their students (see Hodson (1993)).

2.2.8 Implications for teaching science

When considering the role and character of the nature of science in science teaching, McComas, Clough and Almazroa (1998) used many of the arguments put forward above for the why, what and how of teaching NoS. They put it concisely thus:

- NoS to enhance the learning of science content;
- NoS knowledge to enhance understanding of science;
- NoS to enhance interest in science;
- NoS knowledge to enhance decision making;
- NoS knowledge to enhance instructional delivery.

Although they acknowledged that there was no easily recognisable correlation between teachers' views of NoS and their students' understanding of it, they advanced that "bolstering teachers' understanding of NoS is clearly a prerequisite for effective science teaching" (p. 15) and they were disappointed that so few teacher education courses provided effective training in the teaching of NoS when it was widely acknowledged that explicit teaching is necessary. This explicit teaching may be especially successful if it includes a consideration of the historical development of scientific knowledge (Lederman, 1992).

In her study of teachers' beliefs about the nature of science, Brickhouse (1990) examined the possible link between teachers' views of the growth of scientific knowledge and the methods they use to help students construct their knowledge of science. Teachers' differing views of the nature of science resulted in differing classroom practice, not only when teaching NoS explicitly, but also when teaching all other aspects concerning the development of scientific knowledge. This has implications for teacher training, although the study did not give suggestions on how this might influence a teacher's understanding and pedagogical knowledge.

On reviewing literature concerned with improving teachers' understanding of NoS, Abd-El-Khalick and Lederman (2000) found it was generally accepted that there were two components to successful teaching of nature of science: knowledge of the content of the topic, and knowledge of pedagogy. They then introduced a third component: the notion of Pedagogical Content Knowledge for Nature of Science, along the same lines as Shulman's general pedagogical content knowledge (Shulman, 1986). This went beyond understanding NoS and understanding teaching in general, to include "knowledge of a wide range of related examples, activities, illustrations, explanations, demonstrations, and historical episodes" (Abd-El-Khalick & Lederman, 2000, p. 692). They acknowledged that this kind of knowledge often required in-depth experience of teaching a topic, although this went against Lederman's earlier conclusions about the lack of a relationship between length of teaching experience and teachers' conceptions of science (Lederman, 1992). They also emphasized that practical assistance to teachers, probably requiring considerable amounts of time and instruction, was the only way to improve not only teachers' understanding of NoS, but also their teaching of it.

Hipkins and her co-workers (2005) found that teachers tended to ignore NoS in their teaching if the examination of it was lacking (see section 2.2.5). They highlighted that where teachers did teach NoS, it was often based on a naïve understanding of it, linked to empiricist views. They suggested this might be remedied by improved content and pedagogical content knowledge in relation to NoS, although the authors had not seen much research evidence of success. Bartholomew et al. (2004), however, claimed to have seen evidence that this does work. The teachers in their study became more effective as the project progressed, by becoming ever more adept at integrating their teaching “ideas-about-science” with the teaching of scientific content.

It is clear from the international literature that NoS has been studied and considered for inclusion in curricula across the globe for decades. It has been present in the National Curriculum in the UK since its inception in 1989, in various forms and to various degrees. Before looking at the limited literature on the UK implementation of HSW, which has so much in common with NoS, it becomes important to consider the wider context of curriculum development and the influence a curriculum change has on the people involved in its implementation.

2.3 Curriculum development

2.3.1 Curriculum development – introduction

The reasons for and implications of the teaching of NoS have been the subject of research for several decades, as described above. During the most recent two and a half decades the UK has had a nationally prescribed curriculum for all pupils of primary and secondary school age (see chapter 1). Elements of NoS have featured to a larger or smaller extent in all versions of the NC so far, and the effects of the presence (or absence) of these elements have been researched, just like the effects of the presence of other curriculum elements such as scientific subject content. The effects of the most recent curriculum development are the subject of the current study.

2.3.2 Curriculum development – levels of curriculum

For the purpose of this study, ‘curriculum’ is taken to mean “the document setting out goals and intentions across the years of schooling” (Harlen, Bell, Deves, Dyasi, Fernandez de la Garza, Lena, Millar, Reiss, Rowell, & Yu, 2010), commonly instigated by government or other authorities. Inspired by Goodlad (1979), this was called the *intended* curriculum, alongside the *implemented* curriculum, for what teachers do in the classroom, and the *realised* or *attained* curriculum, for what students get out of it – a framework developed for the mathematics curriculum in Canada (Robitaille, 1980). Later, this was introduced into science education (see for instance Robitaille et al.

(1993)). Van den Akker (2003) developed it into the following framework (Table 2.1), with levels 1 to 3 (and sublevels a and b in each):

1. INTENDED	**a. Ideal**	Vision (rationale or basic philosophy underlying a curriculum)
	b. Formal/Written	Intentions as specified in curriculum documents and/or materials
2. IMPLEMENTED	**a. Perceived**	Curriculum as interpreted by its users (especially teachers)
	b. Operational	Actual process of teaching and learning (also: curriculum-in-action)
3. ATTAINED	**a. Experiential**	Learning experiences as perceived by learners
	b. Learned	Resulting learning outcomes of learners

Table 2.1. Curriculum framework developed by Van den Akker - reproduced from Van den Akker (2003, p. 3)

The present study is concerned mainly with teachers' thinking and action at level 2 (both a and b) – their transformation of the level 1b curriculum. Perhaps occasionally a teacher will express a view of curriculum development at level 1a – few teachers have the time and inclination to worry about the vision of the curriculum, most would simply take it from what is prescribed. As a second main part, teachers' assessment of their students' learning is considered, at level 3b.

Alongside a consideration of the different levels of curriculum themselves, the role of the people involved has received some attention. Kirk and MacDonald (2001) described teachers' voice in and ownership of curriculum development in two National Curriculum development projects in Australia. They referred to Bernstein's (2003) structuring of pedagogic discourse in their positioning of teachers in the various fields in which they might have an influence on a developing curriculum. The first level in this structure is "production of discourse" (Bernstein, 2003, p. 57), which, in the case of a science curriculum, refers to the primary production of scientific knowledge by scientists and related practitioners (including philosophers). This level precedes those of Van den Akker's framework. The pool of knowledge produced would be available to developers of a National Curriculum for science, from which they choose that knowledge which may be appropriate to teach at secondary schools. The decisions made at the level of choosing knowledge for school curricula and developing it into curriculum documents is, according to Bernstein's structure, a level of "recontextualisation of discourse", reminiscent of Van den Akker's level 1. This would be the first level at which teachers may be involved, perhaps at Van den Akker's level 1b, alongside education authorities and syllabus writers (Kirk & MacDonald, 2001). Following that, would be a level of "reproduction of discourse", at which many more teachers would be involved, alongside education advisors, for example in trial schools where a new scheme may be piloted (Kirk & MacDonald, 2001). Van den Akker indicated that teachers would be mainly involved at level 2a and 2b, which would include some recontextualisation but mainly reproduction. In Kirk and MacDonald's study a lot of room was given to teachers discussing their feelings about the implementation of such new curricula in their schools, where the specific school context and the pupils they serve became a main discussion area. Bernstein referred to pupils in this context as "acquirers" (Bernstein, 1996, p. 51) of the knowledge which the curriculum is designed to impart. Kirk and MacDonald acknowledged that the main role of teachers remained at the level of reproduction, with very few getting thoroughly involved at the level of recontextualisation, which matches Van den Akker's characterisation of the position of teachers in his framework.

2.3.3 Curriculum development – one context for change

Until the 1960s, curriculum development tended to be initiated and carried out mainly by teachers, individually or in self-organising groups (Fullan, 2000). From then onwards, smaller and larger reforms have been mandated by government regulations, alongside the more private initiatives. Fullan argued that during the first wave of large-scale reform, despite considerable investment in materials and schools, teachers remained largely unreceptive, and "innovations, thus, were adopted on the surface with some of the language and structures becoming altered, but not the practice of teaching." (p. 7). Teachers adapt rather than merely adopt new ideas for use in the classroom (Doyle & Ponder, 1977-78). This, Doyle and Ponder argued, is due to teachers' 'practicality ethics': a teacher will only change if it is practical to do so. Fullan (2000) formalised the description of this process in the context of experience of large-scale reforms, where it became abundantly clear that if teachers did not see the practicality of change, it did not happen. Aikenhead (2006) showed that teachers could advance at least 27 reasons not to implement a specific curriculum change.

Sieber (1972) developed his ideas of requirements for a successful strategy for effecting educational change on the basis of teachers being a varied group of people among which some are Rational Man, some Cooperator and others Powerless Functionary. Strategies based on only one of those images of teachers had failed for various reasons and to various degrees, he argued, hence the need for a combined strategy. Doyle and Ponder, in their work on practicality ethics, related their considerations of teachers' roles to Sieber's classification of teachers. From the change literature they recognised a framework in which teachers were represented by one of three images: the rational adopter, the stone-age obstructionist and the pragmatic skeptic [sic] (Doyle & Ponder, 1977-78). They presented this framework as a spectrum with the rational adopter at one extreme, the stone-age obstructionist at the other, and the pragmatic skeptic somewhere in the middle. This classification has some resemblance to that proposed by Rogers as early as 1962, in his theory of "Diffusion of innovations" (Rogers, 2003) which was developed to describe the adoption of new technologies. The theory suggests that people conform to one of five types: innovator, early adopter, early majority, late majority or laggard. The term 'early adopter' has also been embraced by Ryder and Banner (Ryder & Banner, 2011), along with 'later adopter' and 'reluctant adopter', in their research into teachers' responses to curriculum innovation.

Practicality ethics are surrounded and supported by aspects of personal and professional ethics, which Doyle and Ponder (1977-78) analysed in terms of instrumentality, congruence and cost. Goodson (2001) evaluated the process of change through a larger set of similar factors, and developed a structure for studying them. This structure was formalised in his book *Professional knowledge, professional lives: studies in education and change* (Goodson, 2003).

Goodson (2003) provided a definition of what he considers *external* change, which can be used to examine external influences on teachers: "External change is mandated in top-down manner, as with the introduction of National Curriculum guidelines or new state testing regimes" (p. 87). To investigate *internal* influences in action on teachers within their school, the working definition is: "Internal change agents work within school settings to initiate and promote change within an external framework of support and sponsorship" (Goodson, 2003, p. 87). A variety of *personal* factors are of influence to teachers when they consider their job. Goodson provided a definition: "Personal change refers to the personal beliefs and missions that individuals bring to the change process” (p. 87).

Curriculum development is only one factor, or ‘agent’ as Goodson calls them, of influence on a teacher during processes of change. Teachers’ reflections on the curriculum development investigated in the current study must be seen in the context of all these other influences.

It is now appropriate to investigate what has already been discussed in the national literature about the curriculum development under study: the increased emphasis on *How Science Works*.

2.4 Teaching *How Science Works* (HSW)

As described in section 1.1.2, in 2004 the National Curriculum for science for pupils in key stage 4 (KS4) in England and Wales was revised and given a stronger emphasis than before on HSW. The National Curriculum for KS3 and the subject criteria for KS5 were revised similarly around 2006. Whenever the curriculum changes, the professionals who are affected by the change react in some way. Not surprisingly, teachers want to discuss these changes and some do this through articles in their professional journals such as *School Science Review* and *Education in Science*, published by the Association for Science Education. The following is a review of this literature about the main strands of discussion:

- Section 2.4.1: The role of HSW in the science curriculum;
    - Is the emphasis appropriate?
- Section 2.4.2: Interpretation of HSW in the science curriculum;
    - What does it mean?
- Section 2.4.3-2.4.5: Teachers’ understandings of NoS/HSW and their classroom practice;
    - What are teachers’ own understandings of the nature of science?
    - What are the implications of different understandings of NoS/HSW?
    - Does HSW require specific teaching methods/approaches?
    - What are the implications if these teaching methods are unfamiliar?

  - Teaching ideas/suggestions;
- Section 2.4.6: Assessment of HSW
- Section 2.4.7: Current research into the implementation of HSW in schools in the UK.

2.4.1 *How Science Works* – what is its role in the National Curriculum?

The intended curriculum (see section 2.3.1) reflects the intentions of curriculum designers and course developers. These intentions are documented in the National Curriculum, course specifications, textbooks and examination papers (Osborne, Duschl, & Fairbrother, 2002). From these, the role of HSW in the curriculum must be gleaned. Discussions in the professional literature centre on how this role is perceived, and whether its emphasis is deemed appropriate.

Monk (2006) was positive about the idea that HSW would help pupils to understand the nature of science. He felt that schemes of work can be much improved by looking at them in terms of the question '*What are we doing in terms of the processes of science?*'. In addition to an improved understanding of the nature of science in pupils through HSW, Monk thought that a continuous awareness and active thinking of the processes of science in parallel to working with science subject content was paramount to teachers' development of confidence in their role in science education.

"The teaching of ideas, evidence and argument is what the National Curriculum for science calls 'How science works' [sic]", according to Osborne, Erduran and Simon (2006). They argued that it is essential to give pupils an understanding of how scientific knowledge is produced, and that the way school science portrays the products of science is often far too clear-cut, as if there has been no controversy or argument in their development. Using the tools of HSW, in their opinion, can help redress this.

Based on an understanding of the nature of science through Giere's complex hypothetico-deductive model (see Figure 1.1), Baggott La Velle and Erduran (2007) proposed a model of learning science which takes account of children's general educational development. They saw HSW as a framework to achieve successful teaching and learning of what they referred to as "procedural (syntactic) content" – the knowledge, skills and understanding of how science works both in society and in the laboratory – which has a greater emphasis in the most recent curriculum than ever before (Baggott la Velle & Erduran, 2007, p. 35).

Williams asked: “Will the new GCSE really teach pupils how science works?” (Williams, 2006) and “Do we know how science works?” (Williams, 2007), in relation to our understanding of scientific method and its applicability to secondary school science teaching. He was convinced that “[o]nce we properly teach ‘How Science Works’, it will improve the public understanding of science by removing the notion that science provides proof” (Williams, 2006, p. 15). He noted that HSW was central to the new curriculum, that it required an insight into the philosophy of science, and that “it would be reasonable to assume that the notion of *How science works* has an agreed definition that is consistent across GCSE specifications” (Williams, 2007, p. 119).

Osborne (2008) looked at curriculum developments in the light of pupils’ low engagement with science. He thought that part of the problem was the absence of a link between science learning and young people’s ideals – they seemed to see the link between science and technology, and the potential this offers for a career, but not between science and their personal fulfilment. Osborne promoted a new vision in which science learning should be seen as an education *per se* rather than the first stage of a career, and that it should instil an understanding of “how we know what we know in science, why it matters and how it was achieved” as well as an understanding of science as “a body of knowledge that has transformed the world in which we live for the better and made the material world in which we live comprehensible”, the former of which the author emphasised is exactly *how science works* (Osborne, 2008, p. 72).

So what is the perceived role of HSW, and is the emphasis it receives in the current National Curriculum deemed appropriate? Many people writing about the role of HSW in school science seemed to be accepting of or even enthusiastic about the possibilities of using HSW to improve science learning, particularly in the improvement of scientific literacy. Not all of them were equally optimistic that teachers can get a clear and unambiguous understanding of the philosophy of science as intended for use in secondary schools from the documentation provided to them in the form of the National Curriculum and in the form of course and examination specifications.

2.4.2 *How Science Works* – what does it mean?

With the role of HSW in the science curriculum established, it is important to think about what it actually means: to have to teach about how science works to secondary school pupils. This, together with what teachers actually do in their classrooms (see section 2.4.3), forms the 'implemented' curriculum (see Table 2.1). The implemented curriculum is not necessarily the same as the intended curriculum, as it depends on "individual teachers' conceptions of what the curriculum intends, and their professional judgement about how this might best be achieved" and teachers will look to examination papers in particular to inform their understanding of curriculum intentions (Osborne et al., 2002, p. 18).

In a brief review of the curriculum developments 1989-1999 Baggott La Velle and Erduran (2007) came to the conclusion that school science no longer reflected science as the general public encountered it, and that at the same time it did not provide students with the science needed for university study and further careers. They went on to describe the most recent version of the curriculum, and its corresponding GCSE examination specifications, as representing "a new model" (p. 33). In the authors' opinion it was imperative that teachers understand this model, and how it is exemplified in the examination specifications, to be able to teach it effectively. Not all examination specifications are equally explicit about the targets relating to HSW. Some seem to take a positivist approach, which is not in keeping with the more complex model proposed by Giere (1991). Although Giere's model is not officially taken to underpin the framework of the National Curriculum for science, it is more representative of, and, according to Baggott La Velle and Erduran more faithful to, current thinking about the nature of science than the positivist model, and therefore perhaps more appropriate for teaching science in secondary schools.

Monk (2006) advocated making a clear distinction between the question '*What is happening?'* – requiring description in terms of the facts or laws of science – and the question '*Why is that happening?'* – requiring an explanation in the form of a scientific theory. He was convinced that teachers' own interpretation and understanding of the nature of science is crucial in their successful interpretation of HSW in the curriculum.

Williams (2007) agreed with Monk with respect to teachers' own understanding of the nature of science being of benefit in their teaching of HSW. He questioned the use of 'scientific method' as a notion in the curriculum documents (see also Jenkins (2007)), as it gives reason to believe that there is one such method. And as Baggott La Velle and Erduran reported: there is no clear-cut single interpretation of HSW in GCSE specifications. In fact, Williams found it disturbing that none of the GCSE specifications properly described what they mean by 'How Science Works', while they did make use of words like scientific method, law, hypothesis and theory, and that the only well-described part of *How Science Works* seemed to be how scientific investigations work (Williams, 2006). This, to Williams, was an incomplete view of how science works which skewed the perception of science towards a limited and inconsistent model.

From these discussions, it seems there is no single interpretation of what HSW means, but it is important that teachers formulate their version of what it means, as this will have an impact on how they implement it.

2.4.3 *How Science Works* – how do teachers interpret and implement it?

Teachers' interpretation of curriculum documents and related materials, together with their own understandings of the nature of science and how science works, inform the implemented curriculum. This may include pedagogic strategies, lesson activities and learning experiences which some teachers might not have used if HSW had not been part of the curriculum.

In Monk's words: "science teachers in England are thinking about how they might strengthen their teaching so *How science works* shines through each and every topic they teach" (Monk, 2006, p. 119). To do this, they examine their own understandings of the nature of science and how science works, or take part in research into this topic. Science education researchers run projects to develop ideas about how to teach HSW, either with pupils directly, with secondary science teachers, or both. Often, these projects result in resources for initial teacher training or continuing professional development (CPD).

Williams (2006) suspected that “many science teachers, who have not engaged with the history and philosophy of science, will not have a consistent and clear idea about how science really does work” (p. 14). He was satisfied that GCSE specifications helped teachers to understand how scientific *investigations* work, which would help them teach that particular aspect of HSW, but even the model for scientific method, if, indeed, there is such a thing, was inconsistently represented and therefore potentially unusable for teachers.

Researchers expected that not all teachers would find the curriculum documents and specifications themselves clear enough to allow for successful and effective teaching of HSW. They argued that these documents certainly did not teach the teachers how to do so. For this, many teachers would require some assistance, for example through courses where they might get practical suggestions for teaching.

2.4.4 *How Science Works* – suggestions for teaching

A first, generally applicable approach to teaching HSW would be to inject a running dialogue about the processes of science into each lesson, to make pupils think reflectively about all the activities they are performing when they happen: e.g. observing, and theorising, but also ‘collaborative work’ and ‘peer review’ which are more recent introductions into the curriculum. According to Monk (2006) this might be done on the basis of the teacher’s own understanding of how science works, without having to worry too much about the model portrayed in the specification. A next step would be to develop schemes of work which are consistent across teachers and topics on the deeper epistemological questions of how we arrive at scientific knowledge. As mentioned before, Monk suggested trying to do this by separating the ‘*What?’* from the ‘*Why?’* questions and building an understanding of the different parts of scientific knowledge through those.

In the run-up to the most recent curriculum, Tweats (2006) was developing resources for the teaching of *Ideas and evidence in science*. This was part 1 of Sc1 *Scientific enquiry* in the 1999 version of the National Curriculum for science (DfEE & QCA, 1999), while part 2 *Investigative skills* usually received much more attention and teaching time. The project started with resources for KS3 but Tweats realised that it could be extended to HSW resources for KS4 when the new curriculum came out, as there was a good match between the intentions of *Ideas and evidence* and the project team's ideas for teaching of it, and the intentions of HSW in the new version. They used a variety of contexts, materials and teaching approaches to enable pupils to develop their critical evaluation of evidence, e.g. a debate about evolution and creation, newspaper articles and model data about the effectiveness of facemasks against microbial disease, and the history of the understanding of the solar system through multi-media approaches.

Others have developed teaching ideas relating to *Ideas and evidence* which are directly usable when teaching HSW, e.g. using case studies of scientists and engineers to inspire pupils (Faux & MacDonald, 2006) and working with multiple models (Selley, 2006). Lee, in reference to the curriculum in Hong Kong, suggested that teaching NoS does not have to be complicated: a variety of problem-solving activities and their corresponding nature of science views were proposed, including reference to science being theory-laden, creative, having a subjective element etc. Lee claimed these activities "can be fun for both teachers and students" (Lee, 2007, p. 104).

Akeroyd has presented a wide variety of issues related to the nature of science and how science works in *School Science Review* over the years. Some of his most recent offerings were about the role of enthusiasm and luck in the development of insulin and the Periodic Table (Akeroyd, 2007), and alternative models of the Periodic Table and Lewis theory (Akeroyd, 2008). Insulin also featured in Essex's teaching idea about using its history to illustrate scientific process and ethical issues in drug development (Essex, 2008). This article appeared in a themed issue of SSR 'Science now and then: discovering *How science works*' which was introduced by Williams (2008), a lecturer in science education like Essex. There were no contributions to this theme by teachers – the other contributors were a curriculum developer, a physics author, a philosopher, a science communicator/trainer, and two more lecturers.

In the year 2007 some contributors to *School Science Review* seemed simply accepting of the changes to include HSW in the National Curriculum and then looked for ways to teach it effectively. Gadd (2007) showed how an emphasis on engineering might bring excitement to science lessons, and how this is an excellent exemplification of how science works. Souter (2007) explained that phenology, the study of recurring seasonal phenomena, was an example of a real science which could be used to good effect to show how science works in a real world setting, accessible to secondary school pupils of all ages. Evagorou and Osborne (2007) designed an on-line tool to help with the teaching of argumentation skills, especially about socio-scientific issues. They saw these skills as an integral part of learning about how science works and the improvement of scientific literacy.

A lot of ideas and materials have been announced and provided through *School Science Review* over the years. However, not a great many of those have been suggested by in-service teachers. It also remains to be seen how those ideas reach a significant proportion of in-service teachers, as only a proportion would be reached through *School Science Review* itself. Other routes may be required.

2.4.5 *How Science Works* – implications for teacher training and CPD

Teacher effectiveness is served by the development of seven inter-related categories of professional practice: "content knowledge, general pedagogical knowledge, curriculum knowledge, pedagogical content knowledge, knowledge of learners and their characteristics, knowledge of educational contexts, and knowledge of educational ends, purposes and values" (Shulman, 1987, p. 8). Shulman considered the pedagogical content knowledge of the utmost importance and defined it as "[...] the ways of representing and formulating the subject that make it comprehensible to others [... and] also includes an understanding of what makes the specific topics easy or difficult" (Shulman, 1986, p. 9). If teachers have a varied understanding of the nature of science and how science works, and if the link between teachers' understanding and their classroom practice is complex and varied, it becomes all the more important to help teachers develop these aspects.

When suggesting ideas for the teaching of HSW, Monk (2006) insisted that whole science departments should get together to examine their understandings and the implications for their classroom practice, which he saw as focused, effective, local CPD, necessary "so as to make *How Science Works* explicit and debatable for our learners" (p. 121). There is wider acknowledgement that many science teachers may need CPD at least for certain aspects of PCK, such as discussion, debate, group work, and role-play, although some science teachers were already using these strategies when looking at social and ethical issues (Taber & Riga, 2006).

In the project Tweats (2006) was engaged in, the dissemination of the project materials and philosophy by trainee teachers was pivotal to the success of the project. The experienced teachers at the host schools quickly realised that this was effective CPD for their departments at a time when Sc1 section *Ideas and evidence in science* was to develop into HSW. One of the other groups in the project, at York, stated on their webpage as the first of its aims: "develop teachers' and trainees' knowledge base and repertoires of techniques and skills needed for teaching *Ideas and evidence in science* and the nature of science at key stage 3" (Braund, Campbell, Crompton, Greenway, Ladds, Cook, Carruthers, Dugdale, Smith, Gleisner, Rowntree, Stott, Roupee, Bailey, Hurton, & Taylor, 2006) which resulted in "a community of practice to learn to teach about 'ideas and evidence' in science" (Braund, Campbell, Cook, Ladds, & Walkington, 2006, p. 83). The June 2006 issue of *School Science Review* was dedicated to the theme *Ideas and evidence* and contained other articles which described issues involved in learning to teach about *Ideas and evidence in science*, both for trainees and their mentors (Simon & Maloney, 2006; Taber, Cooke, de Trafford, Lowe, Millins, & Quail, 2006). From Tweats' experiences, there was plenty of reason to think that other experienced teachers would benefit from explicit training in similar ways.

Substantial external CPD is provided by the network of Science Learning Centres around the UK. A discussion paper about CPD of science teachers provided evidence for effective methods and strategies, calling for involvement by *School Science Review* readers in their development (White Rose University Consortium Team, 2005). The impact of CPD at the Science Learning Centres has been reported recently, describing various routes through which CPD to individuals can reach others (Bennett, Braund, & Lubben, 2010). Unfortunately, this report does not contain specific reference to the development of teachers' knowledge and pedagogies regarding HSW, although courses with those aims have certainly been part of the repertoire of the Science Learning Centres.

2.4.6 *How Science Works* – assessment

The third leg underpinning a curriculum is that which is ‘attained’: “the concepts, processes and attitudes towards school subjects that students have acquired as a consequence of their experience” (Osborne et al., 2002, p. 18). Attainment is unique to an individual pupil and insight into it can be obtained through assessment, formally and informally, formatively and summatively, at various stages throughout the pupil’s school career.

There are not many articles in *School Science Review* which refer specifically to the assessment of NoS or HSW. Despite this, a few themes can be recognised: the need for assessment in general and assessment of NoS and HSW in particular, as it tends to spur on teaching, and the need for assessment to match the spirit of the subject.

Although assessment was never meant to direct teaching, ‘teaching to the test’ is practised widely. It is denied by government, but acknowledged by Ofsted and the chief inspector of schools (Marley, 2008). Assessment features twice in a list of ‘tensions’ regarding scientific investigations in schools: “[...]; teaching to the examination or exploiting learners’ interests; [...]; and of course the tension between teaching and assessing” (Monk, 2006, p. 121) but the author did not go into what these tensions entail. Presumably the first refers to the straitjacketing of investigations so they fit exactly with attainment targets and assessment schemes, rather than giving pupils free reign in developing individual investigations to a range and a depth which is difficult to assess within those schemes. Perhaps the second is along the lines of ‘if something is not part of a statutory assessment, it is unlikely that teachers will spend time teaching it’ or otherwise ‘how can investigations be used to teach/confirm/develop certain scientific concepts if they are also to be used to assess skills development?’.

A project involving the Institute of Education and King’s College in London and the universities in York, Keele and Cambridge – supported by the Science Enhancement Programme (SEP) and Key Stage 3 National Strategy (Braund, Erduran, Simon, Taber, Tweats, Peckett, & Johnson, 2006) – was put in place to address the mismatch between the assessment of attainment target Sc1 *Scientific inquiry* and the actual intentions of the two sections of Sc1: *Ideas and evidence in science* and *Investigative skills* (DfEE &

QCA, 1999). It was acknowledged that section 1, *Ideas and evidence*, had previously received little teaching as well as little assessment, for various reasons, not least because of teachers' unfamiliarity with the requirements of teaching about the nature of science (Braund, Erduran, Peckett, Simon, Taber, & Tweats, 2004). After developing materials specifically for KS3, Tweats extended the project at Keele to develop materials for KS4, on the verge of the introduction of HSW into the curriculum. He referred to assessment materials being part of the package but did not describe them at all (Tweats, 2006).

2.4.7 *How Science Works* – current research into its implementation

As the increased emphasis on HSW in the curriculum is recent, not much research into its implementation has been published. Two UK research groups have published their studies into effects of the curriculum change. One research project by Toplis, Golabek and Cleaves (2010) has explored trainee teachers' impressions of the development of teaching of HSW in their placement schools, specifically at KS4. A larger project by Ryder and Banner (2013) has studied the views of teachers in state-funded schools for the 11-18 age range of the changes introduced in 2006 to the key stage 4 (KS4) National Curriculum, including (but without a specific focus on) HSW.

In their study, Toplis and co-workers considered the "uncluttered perspective" (p. 68) of their participants a bonus, as their interpretations were not coloured by previous experience of teaching a different curriculum. The trainees reported an emphasis on investigative aspects of science, communication skills, science in everyday life, some historical aspects and a noticeable reliance on the application of higher order thinking skills. Assessment practices were also seen to feature heavily in lessons, in preparation for both written and practical examinations. Pupils' attitudes seemed dependent on whether they had experienced HSW-like features in lessons at KS3 – pupils who encountered these at KS4 for the first time sometimes needed convincing they were still 'science'. The authors emphasised that the development of higher order thinking skills is essential in the process of gaining an understanding of how science works, and that new teachers need to acquire an appreciation of the requirements of the "philosophy and pedagogy behind the *How Science Works* components" (p. 74) during their training.

Ryder and Banner (2013) also put an emphasis on appropriate professional development, taking account of the need to attend to “multiple goals” (p. 509). These multiple goals are related to the multitude of influences on teachers when they implement change, as described by Goodson (2003). Ryder and Banner found that teachers need to balance their own views of science teaching with the needs of their pupils and the demands their schools and the curriculum put upon them. This, they argued, is more successful when these goals are aligned, either because they happen to be a good match already, or because of developmental work on a teacher’s appreciation of their professional identity which allows the goals to align more successfully.

The views of a wider range of teachers are investigated in the current study, in order to get a more general overview of the kinds of responses found in the secondary school science teaching community as a whole. Teachers in this study are from a range of schools and colleges which are providing for any part of the 11-18 age range, not only in state-funded comprehensive schools but also in the selective, independent and post-compulsory sectors. In addition to this, expert background information is sought from related practitioners who by the very nature of their professional input have an impact on teachers’ practice. These related practitioners, namely textbook developers, examiners and science education consultants, may benefit from the understanding the study might bring to them as much as the study will benefit from their participation.

After the discussion of the national literature dealing with *How Science Works* through the three levels of curriculum, and an appreciation of current research into the implementation of HSW in schools in the UK, it is time to consider where an understanding of the current literature about NoS, curriculum development and HSW might lead.

2.5 Summary

Teachers’ understanding of NoS has been the subject of research in science education for decades, resulting in a vast literature, many curriculum projects, and many instruments to measure, describe and improve this understanding. Despite this, many would say there is a continued misunderstanding of NoS, at least in parts, in teachers as well as in students.

In order to address the teaching and understanding of NoS in the UK, from 2004 the National Curriculum contained a thread specifically emphasising NoS. This thread was called *How Science Works*. Changing the curriculum in such a way most likely has an impact on teachers' practice and their reflection on their practice. Some aspects of this impact can be deduced from the national literature, but persistent in-depth study, similar to that in the international literature regarding teachers' views of NoS, has not yet been performed.

Changing the curriculum also has an impact on the work of related practitioners. Textbook developers, who work with the intended curriculum in order to provide materials for teachers, and examiners, who work with the intended curriculum in order to develop examinations to assess the attained curriculum, have an impact on teachers through the materials they produce. Science education consultants tend to have a more personal impact on teachers by working directly with them to develop their practice.

The methodology for the current study into teachers' practice and reflections on that practice, as well as related practitioners' reflections, is presented in chapter 3.

3 Methodology

3.1 Introduction

In order to study teachers' views and actions in relation to the *How Science Works* (HSW) strand of the curriculum, decisions have to be made about the design of the study and the methods used to collect data. This includes a description and justification of the methods employed, the type of data collected, the development of instruments necessary for this data collection, the sample of research subjects, and the types and tools of analysis of the data.

3.2 Research focus

It is to be expected that teachers react to curriculum changes in some way, and the literature about research into curriculum development (see chapter 2) confirms this. While the curriculum change in 2004 was a change in focus and emphasis rather than a change in content, some response should still be anticipated. In this study the effects of this change on classroom practice are investigated, as well as teachers' views of the change itself.

The aim of the study is to find answers to the following research questions:

- How does *How Science Works* influence science teachers' classroom practice?

  What do they do now that they did not do when HSW was not in the curriculum? Is there something they would not do if it was not for *How Science Works*? How do they feel about that?

- Does the presence of *How Science Works* in the science curricula 11-18 influence science teachers' thinking about the purposes of secondary school science education and approaches to teaching it?

  If so, what is the influence? What are teachers' own views about *How Science Works*? Have teachers' views of science education and teaching changed since the introduction of *How Science Works*?

- Do teachers see the more explicit emphasis on HSW as a positive development, for themselves, for secondary school science education, and/or for their pupils?

If so, why do they think so? If not, what are their reasons?

There is a body of research into teachers' views of the Nature of Science (NoS), how to improve their understanding of the NoS, and what they do in their teaching of it (see, for example, Lakin & Wellington (1994), and Abd-El-Khalick (1998)). Although there are considerable similarities between NoS and HSW, the introduction of HSW is so recent that not much research has yet been published on its effects. An exception is the study into *trainee* teachers' views (Toplis et al., 2010). Another closely related study is the Enactment and Impact of Science Education Reform (EISER) project (Ryder & Banner, 2013). This is a mixed-methods study of take-up of GCSE specifications (quantitative) and teachers' thinking behind the priorities for their course choices and teaching decisions (qualitative), in state funded schools. The current project will attempt to fill some of the gaps left by these researchers, by studying in-service teachers in a variety of schools, state funded as well as independent, and including post-16 providers.

3.3 Research strategy

In order to get a good understanding of what individual teachers do, it is invaluable to be able to talk to them. This will allow the acquisition of the richest possible data from any individual, as it will not only be possible to find out *what* they do and think, but also *why*. Inevitably some people will feel that, while trying to discover what people *do*, it makes sense to observe them in action – 'seeing is believing', after all. However, it is not so easy to observe *why* they do what they do. In addition, it may not be feasible to observe all teachers in a number of lessons in a study of this kind, which would be necessary to ascertain they cover all the aspects of HSW in their lessons. On the other hand, it would be possible to talk about a number of their lessons and discuss the reasons for the decisions they make about those lessons. This is why interviewing is the tool of choice in the study of teachers' views and actions in response to the increased emphasis on *How Science Works* in the science curriculum. Observation of a lesson in which the teacher has planned to address one or more aspects of *How Science Works*, either before or after the interview, is then a logical extension of the data gathering activity, with as many teachers as possible and amenable. If a teacher is observed beforehand, it may provide a seed for parts of the interview in which exemplification is sought of the teacher's actions in lessons, or retrospective confirmation of the teacher's statements in response to questions about their actions. Observation afterwards may also provide this confirmation, while leaving the interview free of presuppositions about teachers' actions on the part of the researcher. The role of informal conversation before the interview and/or observation, when teacher and researcher are introduced to each other, must not be overlooked for potential for bias or other interfering factors, while it is invaluable in establishing a rapport which makes for easier interaction later on.

In the main study, the main method of data collection was semi-structured interviews of up to one hour. These were performed with individual teachers from various schools and backgrounds, in their school, at their convenience. One hour was seen as the maximum a teacher might be prepared to spend on something for which there are no obvious direct benefits to themselves. In many schools, this would mean it would be feasible to carry out an interview in non-contact time during the school day.

Whenever feasible, decided through discussion between the teacher and the researcher, a lesson observation took place before the interview. The opportunity to make links to the observation in the later stages of the interview was seen as valuable so observation-before-interview was chosen in preference to observation afterwards. Further details of the methodology of the main study are discussed in section 3.6.3.

Similarly, and in preparation for the main study, in the pilot study teachers were observed for one hour (or two, in one case – a double lesson with the same class), in a lesson in a normal sequence (no extra or different planning required or desired), which was followed by a semi-structured interview of up to one hour, at school. The pilot phase was also used to assess the feasibility and utility of using observation to collect additional data or to aid the interview. Methodological considerations concerning the pilot study are discussed in section 3.6.2.

In the initial stages of the project, considered to be the pre-pilot study, interviewing technique was practised, taking opportunities as they arose with trainee teachers in the Department of Education and visiting teachers in the Departments of Education and

Chemistry at the University. Thus an interview schedule was developed for use with in-service teachers in their schools. The process is described in full in section 3.6.1.

Ryder and Banner (2013) interviewed a total of 56 key stage 4 (KS4) teachers in 19 state funded schools. From these, they selected 22 for a more in-depth analysis of their interviews. The interviews focussed on the GCSE courses the schools offered, and the teachers' reflections on the impact of the curriculum reform in terms of those courses and their teaching of them. The analysis focussed on the interaction of influences on teachers of which the curriculum reform itself was only one. In the present study, these influences are also examined, but the sample of teachers was taken from a broader population of teachers, and including all three key stages in both state funded and independent schools.

The study into trainee teachers' views of HSW in the curriculum (Toplis et al., 2010) took a rather different approach. Participants were sent a list of five questions four weeks before the end of their final teaching practice, which were intended to focus their attention on HSW and the pedagogy involved. When back at university, the trainees were divided into five groups which focused initially on one question each, after which groups built on the efforts of other groups in turn. The researchers saw the relative inexperience of trainee teachers as a positive, as it allowed them to "view science education in schools from an uncluttered perspective" (p. 68). Be that as it may, and although the researchers' strategy was successful in achieving the aims of their research, one of the foci of the present project is on teachers' perceptions of the curriculum *change* involving HSW, which relies at least in part on teachers having experienced that change for themselves.

In order to further inform the understanding of teachers' classroom practice regarding HSW in the curriculum, the views of practitioners in professions which may have an impact on this practice were sought. These related practitioners, namely textbook developers, examiners and science education consultants, were interviewed with the aid of an interview schedule covering the same topics as the teachers' schedule and using very similar questions, adapted to each specific expertise.

With the overall strategy for the research established, as well as the links with previous research, the specific methods employed in this study need description and justification.

3.4 Methods

3.4.1 Interviews with teachers

As argued above, the most effective way to learn about a person's thoughts and actions is to ask them in an interview. That gives the opportunity not only to ask *what*, but also explanations of *why*, and *how*. It is much more difficult to obtain this kind of information through a written survey, for instance, as most people are more prepared to put their thoughts into a verbal conversation than a written statement, especially if more than a short investment of time is required of them.

In the present study teachers' thoughts and actions with respect to a recent curriculum change were sought. It was imperative to have a certain amount of structure to the interviews, to make sure certain topics were discussed with all teachers so as to satisfy an interest in the understanding of patterns and perhaps discover consensus. Also, this allowed for careful planning and sub-division of the time allocated for the interview, as teachers have only set amounts of time which they can dedicate to anything not directly related to their teaching periods.

For a successful semi-structured interview, a successful semi-structured interview schedule had to be developed. This took careful planning of the themes which were to be discussed, the number of which had to be manageable within the allocated time. Around ten minutes per theme seemed about right, and with a planned maximum interview time of one hour this gave an absolute maximum of six main topics to discuss. The full development of the interview schedule from the initial choice of themes is presented in section 3.6.1, and the resulting full interview schedule in appendix B.

General information was collected about each teacher, such as degree and training background, length of teaching experience, key stages taught and textbooks or commercial schemes used.

Interviews were recorded on a Digital Voice Recorder Olympus WS-200S and transcriptions were performed with Transcriber 1.5.1 (Boudahmane, Manta, Antoine, Galliano, & Barras, 2008). While transcription by researchers themselves allows for an early familiarisation with the data in written form and was therefore seen as the preferred option, to save time a proportion of the transcription was performed by specialists, using their own preferred methods.

3.4.2 Observations of teachers

As the current study is concerned with understanding what teachers *do*, observing teachers in action in the classroom is a natural part of a study into teachers' classroom practice. All teachers were asked if they could accommodate an observation as well as an interview, and as many observations were performed as were feasible regarding timetabling within the allocated school visits. It was decided to collect observational data before the interview. This has implications for whether the observational data can confirm interview findings about the lesson under discussion, or whether that is conceptually awkward. It does, however, aid the interview in that it may make it more likely for the interviewee to be open about their classroom behaviour, and also because concrete examples of classroom activity can be referred to quickly, easily, and better understood by the interviewer.

Observational data was sought mainly as a source of triangulation – a check of the validity and reliability of the interview data – and a means to aid the interviews.

3.4.3 Interviews with related practitioners

3.4.3.1 General information about interviews with related practitioners

Related practitioners here are textbook developers, examiners and science education consultants, whose professional efforts are anticipated to be of influence on teachers, and whose expert knowledge and opinion might provide additional insights into teachers' practice and thinking.

Background information was collected about each interviewee, similarly to that for teachers. For all this included degree background, and length of teaching experience.

Other relevant information was collected, such as which textbooks or examinations the interviewee had recently been involved with. For interview schedules, see appendix B.

3.4.3.2 Textbook developers

It is unclear from the curriculum framework Van den Akker (2003) developed, as presented in Table 2.1, whether textbook developers' efforts lie at level 1b or level 2a. Their products could conceivably be termed 'curriculum materials' as they are often very close to the source of curriculum development and examination specification itself. On the other hand, they could also be termed 'users' of curriculum materials although Van den Akker seems to almost reserve that category for teachers. In most cases, they probably form a layer in between level 1b, the formal curriculum as written by curriculum developers, and the teachers' interpretation at level 2a. As such they play a crucial intermediate role in the interpretation of the aims of the curriculum by teachers. If teachers rely heavily on certain textbooks for their teaching, the developers' interpretation may well have filtered some of the intentions which will then have an effect on teachers' practices. Interviewing textbook developers about their intentions and interpretations sheds light on the function and effect of this link in the chain of curriculum levels.

3.4.3.3 Examiners

Examiners, as examination question developers, play a role at many levels of curriculum. They are next to textbook developers at the interface of levels 1b and 2a. It has also been acknowledged that assessment influences teaching directly (see for example Monk (2006) and Marley (2008)), as most teachers use at least some teaching time to train their pupils in 'exam technique' as well as an understanding of the underlying science. On top of that, examiners are bound to have strong views about the attained curriculum at level 3b, as that is where their efforts are translated into school league tables and pupils' progress and future. Understanding their points of view, of their own and of teachers' roles, adds to an overall understanding of the effects of the HSW strand of curriculum.

3.4.3.4 Science education consultants

'Science education consultant' is a very broad category, potentially including Local Authority Science Advisors, Ofsted Inspectors with science as a specific area of expertise, Science Learning Centre Professional Development Leaders, and perhaps others which might loosely be named ‘science education consultant’. The expectation is that, by grouping them this way, confidentiality agreements may be more easily adhered to.

Many consultants see teachers in action. They have most likely been science teachers themselves, and have views about the curriculum and science which may inform and influence teachers’ views. Their views will be influenced by their own background, professional position and personal views of science.

In the case of Local Authority Science Advisors, their influence on teachers may be very direct – part of their remit is to interpret curriculum documents and examination specifications and develop resources to support teachers in their classrooms. Through interviews with science advisors to teachers in this study, it may be possible to tease out patterns in thinking of groups of teachers from the same school or even the same Local Authority. This will inform understanding of the potential for certain types of continuing professional development (CPD) for teachers.

3.5 Structure of the study - sampling

3.5.1 Interviews with and observations of teachers – sampling strategy

Despite early intentions to approach Heads of Department starting from the top of a randomised list of schools (including KS3/4 schools, KS3/4/5 schools, selective schools, independent schools with at least one of the key stages covering the 11-18 age range, and sixth form/FE colleges) and persuade them one by one to become involved with the study, it became clear very quickly this plan was unworkable as some did not even respond to their initial email. An element of snowballing had been planned from the start: Heads of Department were invited to take part in the study and nominate two of their colleagues, ideally as different from themselves as possible on a number of criteria (see initial contact email, in appendix C). This first recruitment phase resulted in participants from two KS3/4/5 comprehensive schools and one selective school.

Becoming more realistic with time, the sampling turned to convenience, while still stratified to achieve a suitable mix of schools. A number of teachers, mainly Heads of

Department but also other senior teaching members, were recruited, along with colleagues if they could be persuaded. This recruitment was a mixture of email and face to face contact, resulting in participants from at least one school for each type as originally envisaged.

In order to obtain data from a range of different teachers from a range of different schools, sampling then became purposive, with the ultimate aim of a sample which avoided bias. Through email and telephone contact the last group of participants (both subject leaders and 'ordinary' classroom teachers) was recruited. The purposive aspect of the sampling strategy is reminiscent of that of Ryder and Banner (2013), and resulted in a sample of similar size and composition as they used for their publication.

3.5.2 Interviews with and observations of teachers – main study sample

After the pilot study, in which five teachers were observed and interviewed (all female, though this was not planned intentionally) in two local KS3/4 comprehensive schools, the aim for the main study was to interview up to three teachers from at least two schools in each of five school types (for 'school types', see Table 3.1 overleaf).

From the literature there is evidence that data saturation may be achieved from as few as twelve interviews. Guest, Bunce and Johnson (2006) performed a methodological study of a non-probabilistic purposive sample of 60 interviews, in which they cumulatively tested their coding scheme based on sets of six interviews at a time, in order to "systematically document the degree of data saturation and variability of the course of [their] analysis and make evidence-based recommendations regarding non-probabilistic sample sizes" (p. 60). Only 8% of the code categories were added after the first 12 interviews were coded, by which time the coding scheme was 58% stable (58% of the changes to the scheme had been made). The coding scheme was 86% stable by interview 24. For the present study, as the sample is potentially rather diverse, it is prudent to aim for a minimum of three teachers from each school type, multiple schools from each type, and as broad a mix of subject specialism and gender as possible. There is evidence that biologists, chemists and physicists may have differing philosophies of science (Koulaidis & Ogborn, 1989), which may result in different views of HSW and the teaching of it. It is also conceivable that teachers who only teach KS5 have different views from those who only teach KS3 and KS4, for instance.

School type	**School (n=11)**	**Examination results**			**Pupil numbers**		
		% 5A*-C (or equivalent)	**% English Baccalaureate**	**A/AS points score**	**Overall**	**End of KS4**	**End of KS5**
1. Comprehensive KS3/4	A (urban)	50-60	0-10	N/A	800	200	N/A
	B (rural)	50-60	20-30	N/A	650	150	N/A
2. Comprehensive KS3/4/5	C (urban)	40-50	20-30	650-675	1550	250	100
	D (rural)	60-70	20-30	725-750	1300	200	100
	E (urban)	70-80	20-30	1025-1050	1350	200	150
3. Selective KS3/4/5	F (urban)	90-100	60-70	1125-1150	850	100	100
	G (rural)	90-100	60-70	900-925	850	100	100
4. Independent KS3/4/5	H (rural)	90-100	60-70	800-825	850	100	100
	I (rural)	80-90	50-60	900-925	600	100	150
5. FE KS5	J (urban)	N/A	N/A	675-700	N/A	N/A	1000
	K (urban)	N/A	N/A	700-725	N/A	N/A	400

Table 3.1. Schools' details. Performance data and pupil numbers for 2011.

Data were collected between June 2011 and May 2012, i.e. five to six years after the new KS4 curriculum was introduced, by interviewing 25 teachers, from five different types of co-educational school, two or three different schools from each type. The schools were in five different Local Authorities in England, with a varying level of support from Local Authority advisors. For background information of the schools see Table 3.1, and for biographical details of the teachers see Table 3.2 overleaf. 'Urban' and 'rural' classifications were taken from EduBase2 (DfE, 2012a).

Teacher (n=25)	Subject specialism	Degree(s)	Gender	Length of teaching experience (years)	Lesson observation[2]
A1	Chemistry	Environmental Science with KS2/3 QTS	Female	7	×
A2	Biology	Marine Biology / Oceanography	Male	8	×
B1[1]	Chemistry	Chemistry	Male	3	pre-interview
C1[1]	Physics	Physics	Male	11	pre-interview
C2	Chemistry	Chemistry	Female	4	pre-interview
C3	Biology	Zoology	Female	10	pre-interview
D1[1]	Physics	Physics / Astrophysics	Female	10	pre-interview
D2	Biology	Medical Science; MPhil Cardiovascular Medicine	Male	9	post-interview
D3	Biology	Physiology and Human Anatomy	Female	12	×
E1[1]	Physics	Physics / Astrophysics	Male	3	×
E2	Chemistry	Chemistry	Female	8	pre-interview
E3	Biology	Pure & Applied Zoology	Female	12	×
F1[1]	Chemistry	Chemistry; PhD Chemistry	Male	16	×
F2	Physics	Astrophysics	Female	1	×
F3[1]	Physics	Physics / Geophysics	Male	22	×
G1[1]	Physics	Physics	Male	30	pre-interview
G2	Biology	Biology (with Food Science and Nutrition); MSc Animal Nutrition and Biochemistry	Female	21	×
G3	Chemistry	Chemistry	Female	1	×
H1	Biology	Immunology; PhD Microbiology & Pathogenesis	Female	5	pre-interview
I1[1]	Chemistry	Chemistry	Male	28	post-interview
I2[1]	Biology	Biology; MSc Environmental Technology	Male	22	×
I3[1]	Physics	Physics (MSc)	Male	15	×
J1	Biology	Biochemistry; Masters Engineering	Male	9	×
J2	Physics	Chemistry; PhD Physics	Male	11	×
K1[1]	Biology	Applied Biology (BScTech); PhD Molecular Genetics	Male	20	pre-and post-interview

Table 3.2. Teachers' details. Teachers A1 and A2 are associated with school A (see Table 3.1), teacher B1 with school B, etc.

Table 3.1 shows pupil numbers and data from school performance tables as published by the Department for Education (DfE, 2012b), to give some indication of the range of the schools' populations and examination results, and to allow for comparison of schools within each type. Three sets of performance data are presented for each school (where appropriate), namely the percentage of pupils achieving 5 good grades in any GCSE subject (or equivalent qualifications), the percentage of pupils achieving similar success in the English Baccalaureate (a core of academic subjects – English, mathematics, history or geography, the sciences and a language), and the average A-level points score. Data for GCSE are presented in bands of 10% and for A-level in bands of 25 points to preserve confidentiality of the schools. The numbers of pupils on roll for the academic year 2011/2012 were rounded to the nearest 50, again for reasons of confidentiality.

Overall, a good range of schools was reached. Schools in five different Local Authority areas, in three different urban areas and five different towns (classified as 'rural'), were visited, as well as one rural area school. The range of examination results, and therefore presumably the range of pupil intake, is wide. The different schools within each type have similarities as well as differences, but no two schools are so similar that visiting both and interviewing teachers in both might be conceived of as duplication. The data in Table 3.1 are presented to allow recognition that no serious gaps ought to arise in the evidence collected from the teachers, as a good range was visited.

In the main study, around half of the teachers were observed in lessons to allow for continuing checking of the match between actions in lessons and self-report of those actions during interview. Although it would have been desirable to observe *every* teacher to aid the interview (see section 3.4.2), requests for observations made it harder to get agreement for participation in the study so a compromise had to be reached. Two of the teachers were observed *after* their interview for reasons of timetabling, and one teacher was interviewed between two consecutive lessons with the same group of pupils.

The main study sample consists of 25 teachers from 11 schools of five different types. As the initial approach was mainly made by email, this excluded a whole subset of Heads of Department for which email addresses could not be obtained. Further approaches were made by email where possible, but after multiple attempts only those who seemed fruitful contacts, because a reply was received, were pursued further. From then it was decided to only make purposive contact with schools that fit a certain profile, to complement the initial group. This resulted in an overall sample which covers a broad range of secondary school teachers of science in the UK, and is not obviously biased towards any specific group of teachers.

A good mix was achieved of male/female (14:11), biology/chemistry/physics (10:7:8) and range of teaching experience (1-30 years; mean 11.92; median 10). The mean was calculated on values quoted in whole years, and may have included a training year for some and not for others. The mean is certainly below 12, but the majority of the teaching years were from before 2006 when the National Curriculum (NC) for KS4 changed. A large proportion, namely teachers B1, C1, D1, E1, F1, F3, G1, I1, I2, I3 and K1, also volunteered that they have responsibilities as Head of Department, Assistant Head of Department, or Head of Subject.

3.5.3 Teacher data – reasons to believe in the absence of bias

Initially, contact was made at random, through email and in person, with Heads of Department. This resulted in agreement from Teachers C1, D1 and F1 (and their colleagues C2/C3, D2 and F2/F3). After that, approaches were made purposively, by email and telephone.

As the sample is of limited size and there are a number of factors which may influence the participants' views, it becomes important to investigate the potential for a biased sample. Cross-tabulations showing frequency distributions for pairs of factors which may be of influence to a person's position with respect to the phenomenon under study (i.e. teachers' views and practices regarding HSW in the curriculum) are presented below.

Gender vs. Subject specialism

	Male	Female	Total
Biology	5	5	10
Chemistry	3	4	7
Physics	6	2	8
Total	14	11	

Table 3.3. Cross-tabulation of teachers' gender vs. subject specialism

According to the state of the nation report on the UK science and mathematics workforce (The Royal Society, 2007), in 1996 the numbers of secondary science teachers by subject of qualification (biology, chemistry or physics) were 11,300;10,700;10,400 respectively. By 2007 this was much more skewed towards biology, with almost half the science teachers being biologists, just over a quarter chemists, and a fifth physicists. Gender data are not available for England, but taking the Scottish data for 2007 as a guide, 37% of biology teachers were male, compared to 53% of chemistry teachers and 76% of physics teachers.

In the present sample biologists were somewhat under-represented, and physicists similarly over-represented, which was an artefact of the sampling strategy, as the local contacts were specifically asked if a representative from each subject might be interviewed, rather than simply the three most likely volunteers. The contacts were also asked if they could put forward three potential interviewees who were as different as possible on gender as well as subject specialism (and amount of teaching experience), but it was left to them as to how that turned out. As three of the local contacts happened to be physicists themselves (C1, D1 and G1), who put themselves forward, and one other physics teacher was contacted purposively (E1), the seed for over-representation of physicists was sown. The gender balance within the sample of physicists, however, is representative of the national numbers.

The majority of direct contacts, namely nine out of fifteen, were male. This accounts for more than half of the sample being male, as for the rest of the participants they brought to the sample half was male and the other half female, while one male and one female direct contact did not take part in the study themselves. Although there is no reason to believe that male and female teachers' views differ significantly in any way, it is a factor to consider further once the results have been presented.

Gender vs. Length of teaching experience

	Male	Female	Total
<2006	12	7	19
>2006	2	4	6
Total	14	11	

Table 3.4. Cross-tabulation of teachers' gender vs. length of teaching experience

As one of the aims of the study is to gain an understanding of the impact of the *changed* curriculum, a suitably large proportion of the interviewees ought to have teaching experience from before 2006. This was certainly achieved. It is unclear at this point whether the gender ratio is relevant.

Length of teaching experience vs. Subject specialism

	<2006	>2006	Total
Biology	9	1	10
Chemistry	4	3	7
Physics	6	2	8
Total	19	6	

Table 3.5. Cross-tabulation of teachers' length of teaching experience vs. subject specialism

There was a nice spread of subject specialism in both the groups with and without teaching experience from before 2006.

School type vs. Gender

	1	2	3	4	5	Total
Male	2	3	3	3	3	14
Female	1	6	3	1	0	11
Total	3	9	6	4	3	

Table 3.6. Cross-tabulation of teachers' school type vs. gender

From some of the school types only three teachers were interviewed, and it comes as no surprise this means that the occasional subgroup, such as female teachers at FE colleges, was not represented at all. In one FE college only male teachers were proposed, while in the other the local contact, a male, did not succeed in persuading any of his colleagues to also take part.

School type vs. Subject specialism

	1	2	3	4	5	Total
Biology	1	4	1	2	2	10
Chemistry	2	2	2	1	0	7
Physics	0	3	3	1	1	8
Total	3	9	6	4	3	

Table 3.7. Cross-tabulation of teachers' school type vs. subject specialism

Although undesirable, with such a fine subdivision of 25 participants into fifteen possible categories, it seems almost inevitable that some of those categories were not represented, and that several categories had only one representative. Fortuitously, the two chemists in school type 1 and the two biologists in school type 5 were in different schools.

School type vs. Length of teaching experience

	1	2	3	4	5	Total
<2006	2	7	4	3	3	19
>2006	1	2	2	1	0	6
Total	3	9	6	4	3	

Table 3.8. Cross-tabulation of teachers' school type vs. length of teaching experience

Although one category was unrepresented, there were, from each school type, more teachers with experience from *before* 2006 than teachers who only started teaching *after* the curriculum change happened.

Through assigning a three-letter (triplet) code to each teacher representing their gender (M/F), their subject specialism (B/C/P) and indicating their teaching experience by whether they started teaching earlier or later than 2006 (E/L), it becomes possible to study the heterogeneity of the sample in more detail. Table 3.9 gives an overview of the number of teachers in each of the 12 possible triplet groups. The school types in which each of the teachers in these subgroups worked are indicated, numbered according to Table 3.1 above, e.g. ST 34 (for category MCE) means that the two teachers in this category were teaching at a selective and an independent school.

Code	**MBE**	**MBL**	**MCE**	**MCL**	**MPE**	**MPL**	**FBE**	**FBL**	**FCE**	**FCL**	**FPE**	**FPL**
#	5	-	2	1	5	1	4	1	2	2	1	1
ST	12455		34	1	23345	2	2223	4	12	23	2	3

Table 3.9. Overview of the categorisation of teachers according to combined criteria of gender, subject specialism and length of teaching experience. # = number of teachers in each category; ST = school type

From Table 3.9 it is clear that not all categories are equally represented. On the other hand, there is no clear bias towards or away from any of the categories or school types. Within the largest categories, MBE and MPE, four of the five school types are represented. Only one category is missing altogether. As the study is seeking an increased understanding of the effects of a curriculum change, it is only right that the sample contains relatively more participants who have teaching experience from *before* the change, and therefore perhaps not a full complement of teachers in the categories representing shorter experience. Similarly, because of the relatively small number of teachers interviewed in these groups, school type 1 is not represented by a physicist (although there were two physics teachers in the pilot study), and school type 5 has no female participants in the study.

A visual representation of Table 3.9 is presented in Figure 3.1.

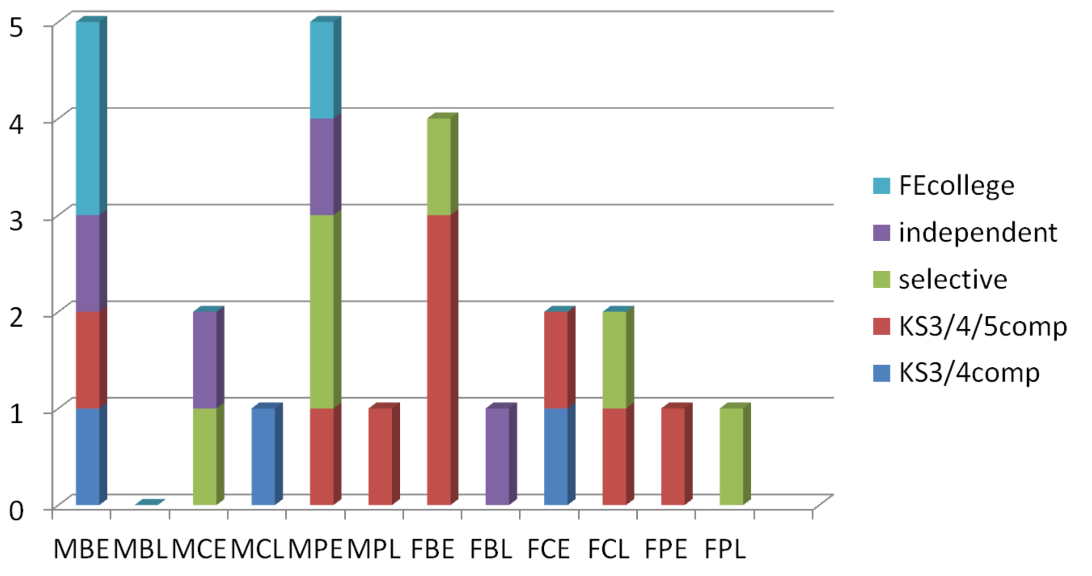

Figure 3.1. Overview of the categorisation of teachers according to combined criteria of gender, subject specialism and length of teaching experience

One additional feature of the sample becomes clear from Figure 3.1, although it might have been discerned from Table 3.9: a disproportionate number of the female teachers in the sample happen to be teachers with long experience who are working in KS3/4/5 comprehensive schools. Mitigating is that they are in three different schools.

Similarly to the overall sample of teacher interviewees, there is no clear bias towards or away from any of the categories of teacher, school type, lesson subject or key stage in the observed lessons.

3.5.4 Interviews with related practitioners – main study sample

Semi-structured interviews were performed with six textbook developers, two examiners and three science consultants. A few of the interviewees have been professionally involved in more than one of the occupations described (and perhaps others), but the interviews were focussed on the function under consideration. Only occasionally did their other roles come to the fore in the interviews. All interviewees have been UK secondary school science teachers for varying lengths of time in the past. The number of interviews with others was not intended to overshadow the interviews with teachers, and a balance was reached with eleven other interviews.

Six textbook developers, who were involved with textbooks for some or all of the age range of KS3, KS4 and A-level, linked with a variety of exam boards as well as general ones not linked to any exam board in particular, were interviewed for around 45 minutes. For reasons of confidentiality, extensive biographies of the interviewees cannot be given here. Table 3.10 gives a limited amount of background information of each interviewee.

Interviewee	Subject background	Main involvement currently	Age range involvement
TD1	Biology	Context- and concept-based courses	All
TD2	Physics	Context- and concept-based courses	All
TD3	Chemistry	Concept-based course(s)	All
TD4	Chemistry	Context-based course(s)	A-level
TD5	Physics	Context-based course(s)	A-level
TD6	Biology	Context-based course(s)	A-level

Table 3.10. Limited background information of textbook developers

Two examiners were interviewed for around 45 minutes. They were involved with two different examinations: one for GCSE Physics, the other for A-level Chemistry. One had been involved with another examination in the past. Both were also interested in and associated with the curriculum and textbook developments linked to the examinations they were involved with.

Interviewee	Subject background	Main involvement currently	Age range involvement
EM1	Physics	Context-based course(s)	GCSE
EM2	Chemistry	Context-based course(s)	A-level

Table 3.11. Limited background information of examiners/moderators

Three science education consultants, supporting science teaching in separate areas of the North-East of England, were interviewed for around one hour.

Interviewee	Subject background
CA1	Physics
CA2	Biology
CA3	Biology

Table 3.12. Limited background information of consultants/advisors

The sample of related practitioners started from convenience and grew through snowballing. Some of the interviews were conducted over the telephone rather than face to face.

3.6 Structure of the study – data collection

3.6.1 Pre-pilot study

3.6.1.1 Introduction

During several months before the data collection for the pilot study (see section 3.6.2), interviewing was practised with fourteen teachers and trainee teachers, using various versions of a developing interview schedule.

3.6.1.2 First phase of interview schedule development

The first two interviews were purely exploratory, to get an understanding of what goes on while interviewing, and some of the practical parameters involved. It turned out to be highly useful to have full view of a clock, for instance. It also became clear, from the very small sample, that some teachers are more than happy to talk, when simply given opportunity, while others need more guidance and clear, appropriate questions.

3.6.1.3 Second phase of interview schedule development

In order to obtain similarly usable, quotable data from all teachers about similar issues, the need for a more structured interview schedule became obvious. As there is also the need for rich data from personal views and opinions, the interview cannot be and does not need to be rigidly structured, so an interview schedule was developed around six main areas: familiarity, understanding, practical implementation, teaching methods, outcomes/assessment and personal views. An overview of the types of questions in these areas is given below.

1. **Familiarity**: To what extent are you familiar with *How Science Works* as it is in the curriculum, and how did this come about?
2. **Understanding**: What are the main elements of *How Science Works* in the curriculum, and has your interpretation of this changed since you first came across the term?
3. **Practical implementation**: What kinds of things do you do to teach *How Science Works*, is there any variability across the age ranges you teach, and how does it compare to any other teaching you do?
4. **Teaching methods**: Do you use any different teaching approaches for *How Science Works* compared to your other teaching?
5. **Outcomes/assessment**: When you teach a particular aspect of *How Science Works*, how do you judge what your pupils have learnt, and is your teaching influenced by assessment in any way?
6. **Personal view**: What is your own view of how science really works, how does this view compare to the curriculum view, do you consider the increased emphasis on *How Science Works* in the curriculum appropriate and/or successful, and what are the effects on your pupils?

A flow chart type structure, with if... then... else... as a basis, seemed appropriate. This was tested with three trainee teachers, resulting in interviews of 40-50 minutes in length. This seemed a suitable length to aim for in the pilot and main study interviews, so the six main question areas were kept while the questions themselves were developed further.

3.6.1.4 Third phase of interview schedule development

Interviews of varying length were tried, with a schedule adapted appropriately. The key area under development was "what do teachers do to address *How Science Works*, and what would they not do if it was not in the curriculum?" To explore the effectiveness of questions in this area, eight teachers who visited the Department of Education for a development course were interviewed for anything between ten and thirty minutes.

During this phase:

- questions about views and opinions were included at a later stage, and in the latter part of the interview schedule;
- questions were reformulated to increase clarity;
- questions were refined to achieve a reproducible conversational style;
- questions were refined to become more open-ended. It is all too easy to fall into the trap of asking a question which can be answered with "Yes" (or "No") without elaborations and without any quotable phrase being offered.

3.6.1.5 Fourth phase of interview schedule development

Around the same time as the last developmental interviews, one in-service teacher was interviewed in an authentic setting at school, to test the full interview schedule. Interruptions, such as school bells, teaching colleagues and form group pupils, are a little disruptive during the interview itself but probably unavoidable when interviewing inside a school. Thankfully, the digital voice recorder was so sensitive that it was always possible to transcribe nearly 100% of the conversation, even if the interrupting noises were quite loud.

3.6.2 Pilot study

Through the trial-and-error of what is here named the pre-pilot study, the interview schedule developed into a consistently usable guide, yielding good quality data. It provided the basis for interviews which could reliably be performed within around 40 minutes, but also allowed for extension to over an hour if the teacher's schedule permitted.

In the pilot study, all teachers were observed in a lesson in which they had planned to address at least one aspect of *How Science Works*. This gave the opportunity to check the match between what teachers say they do during the interview and what they actually do in the classroom, and to get a general feel for what happens with regards to *How Science Works* teaching. It encouraged the teachers to be open about their activity in a gentle way, and allowed for easy links to that activity during interview. All observations took place *before* interview.

During the pilot study interviews, it became clear that teachers were forthcoming with examples of their practices, often without being prompted to supply those. These always matched the spirit of the observed lessons. This was one of the reasons to be less pressed to observe all teachers in the main study.

3.6.3 Main study

For the interviews with teachers, it becomes important how we judge 'data saturation' (see section 3.5.2). It is also important to achieve a good mix of respondents, as there are so many different types of schools and courses which, with other factors such as subject background and gender, might all have an influence on teachers' views.

All interviews were performed in school, often in the teacher's main classroom during non-contact periods. Interviews were audio-recorded and transcribed, ready for analysis.

On the basis of experience from the pilot study, observation was not done with all participants, as the pilot indicated that it does not add as much to the data as the organisational load would require. Observations were done when they could be organised easily, to provide a gentle way of encouraging teachers to be open about their practices, and to keep an eye on the notion that it really confirms teachers' ideas about the main strands of *How Science Works*.

The interviews with related practitioners were performed face to face where practical, and over the telephone where travel distance prohibited face to face interviewing. The first interview was initially treated as a pilot interview, in order to ascertain whether any significant changes would need to be made to the interview schedule. In the event no changes were necessary, so it was deemed appropriate to include the first interview with the main study data as there was a limited number of accessible potential interviewees. Telephone interviews were audio-recorded and transcribed as before. Consent forms from telephone interviewees were obtained electronically, ahead of the interviews.

3.7 Structure of the study – data analysis

3.7.1 Observational data

The data from the lesson observations were mainly used as hooks and probes during the interviews, and not analysed separately. For reference, some details of the observed lessons are included in appendix D.

3.7.2 Interview data

The analysis of qualitative data from the interviews was exploratory and descriptive in nature. Initial data analysis, of the pilot study data, was done through Grounded Theory (Glaser, 2002; Glaser & Strauss, 1967; Strauss & Corbin, 1997) principles, looking for emergent themes. This was done without any stringent coding scheme but with some expectations of themes, because the amount of data was deemed small enough. Interviews were not all transcribed fully in the first instance, and analysis was done from notes and partial transcripts. A number of themes emerged, which were taken into account when main study data analysis started.

The main study data, a larger bulk, needed a more systematic approach, through software. Although it is acknowledged that software does not automatically enhance the quality of the data analysis, the opportunity to work in an electronic environment was very attractive. NVivo (QSR International Pty Ltd, 2011) software was used, as software and some support were available through the university.

As it is almost inconceivable that one type of behaviour fits all teachers for all aspects of the current study, but it is also unlikely that every teacher is unique, the grounded theory approach to the analysis was overlaid with a phenomenographical perspective. Phenomenography was primarily developed to study learners' experiences of learning, and their developing thinking (Marton, 1981). It is eminently suitable to studying the full range of people's experiences of phenomena, such as the present study of science teachers' experiences of curriculum change and the specific change of emphasis and aim of the new curriculum. It is used to arrive at the qualitatively different ways in which people experience such phenomena. Teachers' views will vary, but there are likely to be a limited number of such different views, and it is not necessarily easy to see how these will be correlated to their background or professional position, or any other factor such as gender, although all these factors are considered in the analysis. It is tempting to categorise beforehand, for example to assume that young, newly qualified teachers have a fresh view of HSW in the curriculum, uncoloured by experience of earlier versions of the National Curriculum, and are therefore more enthusiastic about it. On the other hand, the overview of a seasoned teacher may lead to recognition of a potentially more fruitful curriculum approach and design, and thus renewed enthusiasm to try out new teaching. As there are multiple factors influencing teachers' views, studying the full range of views at the group level may be more productive than looking for patterns in individual responses, or trying to understand a phenomenon as a common experience of a group of people. This is where phenomenography distinguishes itself: it allows for a description and analysis of heterogeneous experiences of a potentially heterogeneous group of study subjects of the same phenomenon (Marton, 1981). This prevents the problems Koulaidis and Ogborn encountered in trying to find commonality or clustering in the philosophical views of each sub-group of science teachers (Koulaidis & Ogborn, 1989).

There are obvious links to the studies of teachers' views of the Nature of Science and how these influence their teaching (for example, Abd-El-Khalick et al., 1998; Brickhouse, 1990), although their approaches were vastly different. The insights gained from the present study will add to those reported by Ryder and co-workers (Banner, Donnelly, Homer, & Ryder, 2010; Banner, Ryder, & Donnelly, 2009; Ryder & Banner, 2011, 2013). While their research questions were different, as they were looking to understand teachers' views and teaching of GCSE courses in the light of student take-up of those courses, they have developed ideas about the influences on teachers' interpretation of curriculum documents in the process of their research. These are compared with the results from the present study.

In the initial phase of analysis of the main study data, a grounded theory approach resulted in an overwhelming set of codes (interesting and important pieces of data) coded at an unhelpfully vast array of nodes (the categories). 'Assessment', for example, was applicable to a number of utterances so varied that categorising them all as 'assessment' was more distracting than helpful.

A different approach was required: a further pass through the data, with the opportunity to carefully think through the merits of each piece of data afresh. This resulted in a much more manageable set of nodes as described in Table 3.13 overleaf.

In this second pass, the data was coded at nodes relating directly to the research questions and sub-questions, an approach recommended by Vulliamy and Webb (1992). Shortly after this pass, Ryder and Banner's (2013) paper came into the public domain. This provided an insight into a framework of influences on change developed by Goodson (2003), which were an almost perfect match for the influences already assigned as described, albeit from a different viewpoint. Goodson's 'personal agents' almost matched the category RQ2-external-influence, his 'internal agents' show an uncanny resemblance to RQ2-indirect-influence, while his 'external agents' had a large overlap with RQ2-direct-influence. Another pass through the data removed the differences between the two, and gave another opportunity for checking consistency.

The same approach, with the nodes directly related to the research questions, also proved suitable for the coding of the data for the related practitioners.

Although NVivo allows for far more detailed coding and recoding, it was felt that the analysis structure reached was sufficient to use directly in the report. Subdivisions and groupings were decided once codes were collected together, and analysed further as the results were written up.

Node	Description	Example code
RQ1-change	evidence for teachers' appreciation of a change in their practice, as a result of their changing understanding of HSW requirements (either around or since 2006)	"So at that point we were 'oh well great, we are going to have to change things anyway so we will change them to the way that we want to change them'" (C1, 13-14)
RQ1-current	evidence for teachers' current practice	"But again it was introduced very quickly, for putting into your schemes, so it tended to be taught in bolt-on packs at the end, rather than, as it's now, the integral one" (E3, 35-37)
RQ1-feel	evidence for teachers' feelings about their practice and the influences thereon	"it's not really appropriate for me to say because I've still got to teach a couple and I'd rather not" (C3, 390-391)
RQ1-influence	evidence for teachers' perception of influences on their practice (e.g. courses, both in-house and external)	"it was quite a big part of our training" (G3, 6)
RQ2-current	evidence for teachers' current thinking about science, and teaching science	"It's just the application of science. It's the application of data, once collected" (G2, 370)
RQ2-direct-influence	evidence for teachers being directly influenced in their thinking (about science and/or teaching) by (aspect(s) of) HSW in the curriculum	"I think you can't really disagree with any of this list really I think it's all what should be on a curriculum, but it's part of a curriculum it should be inherent in the way it is delivered and in the way you teach" (J2, 161-163)
RQ2-indirect-influence	evidence for teachers being influenced in their thinking (about science and/or teaching) by clearly school-related developments outside HSW in the curriculum (e.g. Assessment for Learning etc.)	"Around the time of HSW there wasn't an emphasis on the PLTS skills, although we did try to have an emphasis on that, to try to get more of those personal learning thinking skills, but I think it is still there but there isn't a great focus on it" (F1, 375-377)
RQ2-external-influence	evidence for teachers being influenced in their thinking (about science and/or teaching) by factors outside their school life (e.g. family, their own schooling and/or degree etc.)	"at university it was like facts and I don't think there was a history course, or anything" (E1, 243-244)
RQ3-positive	evidence for teachers' positive attitude towards the emphasis of HSW in the curriculum	"I think by going back and focusing more on the skills, rather than the content, we'd get them back on track" (A1, 114-116)
RQ3-negative	evidence for teachers' negative attitude towards the emphasis of HSW in the curriculum	"probably not much at KS5 at all, we just don't have time" (H1, 49-50)
RQ3-on-balance	evidence for teachers' attitude towards the emphasis of HSW in the curriculum being either neutral, or being a bit of both	"that kind of evaluation thing. There would need to be content, either before, in a prior lesson, or during. It may not be the main focus, but there would need to be content as well, because you can't evaluate unless you understand" (E2, 268-271)

Table 3.13. Nodes and codes for the second pass through the main study data

3.7.3 Data quality, validation and triangulation

The data gathered from three sources – interviews with teachers, observation of teachers and interviews with related practitioners – allow for a certain amount of triangulation which enhances the quality of the resulting conclusions. It is imperative in this study to make a distinction between data triangulation and methodological triangulation

(Denzin, 1970). A limited level of methodological triangulation is possible, as more than one method was used to collect data from the main subjects, the teachers. As not all teachers were observed, one side of the triangle is incomplete and the best use of the observational data was as support material for the interviews rather than for full triangulation. Data triangulation becomes important when considering the data from different types of people, namely textbook developers, examiners and consultants as well as teachers. As they have a different perspective of a teacher's experience than the teachers themselves, these data will be of a different level compared to each other, resulting in different complications for triangulation. Only the parts of teachers' practice about which each related practitioner can be seen to have some expertise can assume a supportive role in triangulation.

Bell and co-workers (1998) were critical of the use of interviews as a primary data source for the gathering of data about teachers' actions, and advocated the use of observations to provide triangulation to support the validity of any conclusions. They warned about the pitfalls of performing observations with foreknowledge of teachers' views (of the nature of science in the criticised study in question) and suggested that observer bias be prevented by performing observations without any knowledge of the beliefs and intentions of the teacher. Performing observations before interview, without any detailed contact with the teacher beforehand, should ameliorate this situation. Moreover, as the current study is investigating the *why* and *how* of teachers' actions as much as or even more so than the actions themselves, the role of the interviews as primary data source is strong.

The discussion about validity (and reliability) of data developed in the community of quantitative researchers, and many of the measures are inappropriate for direct use in relation to qualitative research. Despite this, a discussion of data quality and triangulation must be accompanied by a discussion of validity, as it has a bearing on how to decide whether what is actually measured is what was desired to be measured, with a degree of confidence. This (internal validity) and the potential for generalisability (external validity) are aspects of validity of concern in this research. The data from this study intuitively led to a theoretical framework similar to Goodson's. As it was also used by researchers in a similar study (Ryder & Banner, 2013), providing results and conclusions in similar directions although there were also differences, the data can certainly be considered to be valid.

A final consideration regarding data quality is the validation of the analysis process. In order to achieve inter-coder reliability, Vulliamy and Webb (1992) recommended: “If possible ask a team colleague to code an interview transcript or fieldnotes according to the rules that you are operating” (p. 217). Fellow post-graduate researchers were approached to perform this function.

3.8 Summary

In a study of teachers’ actions and views in response to a curriculum change, interviews are the method of choice to collect the rich data required to form an understanding. Observation certainly has its place, but observing one lesson is unlikely to give a representative impression of a teacher’s classroom practice regarding an aspect of teaching science as broad as HSW. In a relatively small study like the current one it is more fruitful to use observations to aid the interviews, as teachers are forthcoming with richly descriptive examples of a number of their lessons.

Textbook developers, examiners and science education consultants will also have responded to the curriculum change in some way. Gaining an understanding of the views and actions of these related practitioners, again through interviews, provides additional insights into the impact their practice has had on teachers.

The resulting data collected from teachers are presented in chapters 4 to 7, and those from the related practitioners in chapter 8.

4 Teachers' reflections on their classroom practice

4.1 Introduction

The most important outcome of this study is to know whether or not the increased emphasis on *How Science Works* (HSW) has had any impact on teachers' classroom practice, and what that impact might be (research question 1). The evidence regarding teachers' perceptions of the change in their practice is presented in section 4.2. Description of what they say their practice now entails follows in section 4.3. The full text of *How Science Works* at each of the key stages is included in appendix A for reference.

Throughout this thesis, quoted sections of the interviews are accompanied by line numbers in brackets. When specific words were spoken with emphasis compared to the rest of the quote, these words are put in italics. Unfinished utterances are indicated with an ellipsis. Square brackets indicate the replacement of unclear references (usually with earlier phrases used by the interviewee, sometimes paraphrased or interpreted), or, occasionally, a small insertion for clarification. An ellipsis in square brackets indicates deletion of superfluous words or phrases.

The teachers, when asked whether their classroom practice has changed at all because of the increased emphasis on HSW in the National Curriculum and the A-level Subject Criteria (NCASC), could be divided into three groups. There were those who said something akin to "I was doing it all along", those who said it has certainly brought changes, and those who initially said they were doing (some of) it already but started to qualify their answer almost immediately and ended up somewhere in the middle. For easy reference later on, these groups will be called "doing-already", "changes-certainly", and "doing-some-already-but", respectively. This classification is explored in sections 4.2.1-4.2.3. In addition, section 4.2.1 introduces 'the spectrum of readiness to change', which encompasses a range of attitudes of how teachers approach a change such as the one under study. As the attitudes of the teachers in this study do not cover the full range, 'alternative outlooks' are explored in section 4.2.5.

As the change in teachers' practice plays such a crucial part in a study of a change in curriculum, this change is examined first, and the views of the teachers who acknowledged that the curriculum change has certainly brought changes to their teaching, are presented first. Teachers who started teaching after 2006, and can therefore not be said to have *changed* their teaching because of HSW, have been excluded from the analysis for this section. This applies to Teachers B1, C2, E1, F2, G3 and H1. This is not to say that these teachers have not changed since they started teaching, or that HSW has not had an influence on them – all but one readily talked about changes they have made or undergone in their teaching. They *are* included in the analysis for section 4.3, where current practice is presented.

Teachers mentioned certain aspects of HSW instinctively at the beginning of our interviews. These initial 'commitments' are investigated in section 4.3.1 before a more extensive exploration of the various aspects of HSW in the following sections. The observed lessons are briefly discussed in section 4.3.2.

As outlined in chapter 1, there are three main elements to HSW in the curriculum (be that at key stage 3 (KS3), KS4 or KS5): the investigative and practical aspects (abbreviated 'I', explored in section 4.3.3), the history and philosophy of science (HPS, further abbreviated 'H', explored in section 4.3.4), and the socio-scientific aspects (abbreviated 'S', explored in section 4.3.5). Communication skills, as also described under the heading of HSW, sit somewhere on the boundary between the first and the third, and are important to all three. In addition to the separate sections of HSW in the curriculum, there are a few other elements to the teaching of science and HSW, namely skills, assessment, and the use of commercial materials (textbooks etc.), which were prominent in the early stages of most of the teachers' interviews.

All but one of the teachers mentioned 'skill(s)'. The references to 'skills' were numerous and varied, and will be presented more fully in section 4.3.6. Teacher J2, who taught physics at a Sixth Form College, was the exception, not using the word 'skill' at all. He was probably also the most extensively philosophical during our interview, referring to "Karl Popper" (71) and evidence being needed to disprove rather than prove a theory, and one of the least interested in the formulaic use of practical skills, as he explained: "I have realised that rather than just go through this ritual [of pupils simply following a teacher-developed task sheet and getting on with it] they have got to try and engage with that process of designing" (125-127).

Reflections on practice referring to assessment and textbooks (and related commercial materials) are considered in sections 4.3.7 and 4.3.8 respectively.

Finally, as teachers also mentioned ignoring one or other aspect of HSW, giving a variety of reasons, this is explored in section 4.3.9.

4.2 Changes to teachers' practice

4.2.1 "Changes, certainly"

Almost half the teachers with experience from before 2006 (namely A1, C1, C3, D1, D3, E2, F1 and J1) were ready to acknowledge that HSW had brought certain changes to their practice, although for some it took some serious thinking to come up with examples.

Teacher C1 was the most obvious example of a teacher who was more than ready for the curriculum change in 2006. His department had already started revising their KS3 curriculum around 2003 because they "wanted it to be skills based" (7-8). For a fuller discussion of teachers' mention of 'skills', see section 4.3.6. Teacher C1's department "were doing a lot of research into other schools that were implementing a two-year KS3 at this point" when they discovered that "a lot of schools were holding back with their two-year KS3 because there was news of the new National Curriculum coming out which was going to be much more HSW based" (8-12). They pressed on with their change, and "looked very detailed at the Core Science and where overlap was in KS3. What was left in KS3 was skills the kids needed in Year 9 to start KS4", so they built their "curriculum in Year 7 and 8 based on what wasn't covered in Core" (27-29). Apart from concentrating on skills, which initially was dominated by skills related to practical work but was expanded to other activities relevant to everyday life and science in the news, C1's department realised that "certainly the research type of things [where pupils search for information about a certain topic, especially in relation to the GCSE controlled assessment] was something [they] weren't really doing, and also the little bit about scientific jobs" (194-195). To practise these research skills, C1 developed an activity for his year 10 where they were to write an article for a fictitious magazine about the properties and uses of different forms of radiation, with access to laptops to do the research and produce the article. This activity was new to the GCSE scheme. C1 added:

> "It certainly was the most fun writing schemes of work we had had in 2006; it was the most fun because we really did feel as though we were throwing away a lot of dusty old stuff we didn't want to do and were forced to do, and we had the freedom to run with it." (C1, 474-477)

That last sentiment, of seeing the new National Curriculum (NC) as justification for what they had wanted to do for a while anyway, was also expressed by Teacher D1. She expressed a sense of liberation from a curriculum perceived to be overloaded with scientific content: "I suppose the big impact that it has had on my teaching is that I feel like I am not constrained anymore" (361-362). About one of the things she feels free to do now, she said: "now if I am setting lesson objectives I will set skills as objectives, they are as much part of the lesson and part of the learning" (48-49). It might be said that D1 was ready to embrace the new curriculum.

One teacher, namely Teacher J1, even mentioned 'embracing' the change in so many words:

> "As a teacher I want my kids to pass, so I have taken a vested interest in HSW, and what I have tried to do is not have it as 'oh I have got to tag it on' and think of it as part of my teaching. I don't know if I am still in transition of thinking 'yes, I have to do it because of ...' or if I *embrace* it and use it, but it has to be included." (J1, 251-255, emphasis added)

To illustrate this new HSW teaching, J1 described two activities he has used to get his students to appreciate the skills scientists use to communicate their ideas, namely conference presentations and peer review:

> "There are occasions where we give them opportunity to do a presentation; in that case you fragment the topics into different bits so that their source of information they can give to the class. And sometimes they have peer assessment in terms of marking each other's work in terms of an exam question." (J1, 191-194)

Teacher F1 was another example of a teacher who was ready to embrace the changes as they happened. He referred to the precursors of HSW:

> "Tracking right back to when I started teaching we didn't call it HSW, people would refer to it as Sc1 or AT1 which was basically science investigations, just the skills to do scientific experiments. And then I suppose it was five-ish years ago, something like that, it expanded out to cover other areas of scientific skills besides just doing investigations and really that is when it became known as HSW. And then I think it has become a much bigger focus at all key stages whereas before it was just doing investigations." (F1, 7-12)

He also pointed out that the non-investigative elements of HSW had been part of previous incarnations of the National Curriculum, which he thought "was referred to earlier as Sc0, [and which he had] a vague recollection that it was the bit that came before Sc1 but until this version of the National Curriculum [wasn't] particularly explicitly taught but it was there" (40-42). He has welcomed the change and the opportunity to teach HSW explicitly, but added "I still don't think there is enough emphasis on, if you like, the old Sc0, this idea about models and theories" (554-555).

The new aspect of literature research which pupils have to learn to do as part of the GCSE controlled assessment was something that Teacher A1 also mentioned as one of the more obvious changes that HSW brought: "I think that's been probably the biggest change recently, the amount of research" (38-39). She also perceived a change in her use of 'models' in teaching. She said before HSW she "would have used a model to show something, to explain something, but [she] would never have thought of getting the kids to make their own models and evaluate them" (293-295). She was not convinced that the changes have been as big as she initially thought, but she did say: "we're a lot more conscious of making sure we hit all those targets" (140-141).

Despite the need for change that this "changes-certainly" group of teachers perceived more urgently than the other groups (see sections 4.2.2 and 4.2.3), there are some aspects in which they did not distinguish themselves, such as that HSW is part of good teaching and that it was nothing to be afraid of. This was vocalised passionately thus:

> "It certainly wasn't as hard to implement into the curriculum as people fear every time there is a change, because if you are doing a good job, and I think we were doing a good job generally, that actually when it came to the crunch, we sat down and went 'oh well we do that and we do that and we could do that'." (C1, 105-108)

Although the teachers in the "changes-certainly" group were all ready to acknowledge their practice had changed as a result of the new curriculum, their approaches to the change can be seen as a spectrum. Teacher C1, for example, leading his department in the change towards a scheme of work which was much more geared towards the teaching of 'skills', which were to become a crucial part of the HSW curriculum, a few years ahead of the required time for change, can be assigned the label of 'pioneering'. On the opposite end of the spectrum of teachers presented so far was Teacher A1, who was apprehensive of the new curriculum at first and quite unsure of the changes required, but saw the need for change and did persist with that idea, so can be assigned the label of 'following' – a label reserved for teachers who adopted the change as late as possible, following everyone else. In between those two extremes were Teachers D1, F1 and J1, who relished the opportunities the curriculum change provided for their teaching as soon as the paperwork announcing the required changes started to reach them, and can thus be assigned the label of 'embracing'. The other three teachers in this group can be assigned on the spectrum as follows, based on evidence which was typical for their position and represented the overall impression they gave in our interviews (and observation, if performed):

- C3, who was in C1's department when the changes happened, was not quite as adventurous as C1 although she seems of the embracing type, as she said: "I think if you're going to teach science, and teach it properly, you would do this anyway. So I wouldn't say that I would've missed anything out really. I maybe wouldn't have focused as much on careers, but I'm interested in that anyway" (122-124).
- E2 is an example of a 'follower': "I think gradually, as the exam syllabus is changed, and brought more and more of that kind of thing in, and the demand, and the way that they're evaluating it, is changing" (74-76).
- D3, who joined D1's department after 2006, is a 'follower', as she said: "It's one of those things that's been pushed through, so you do think about those things a lot more than you did" (122-123).

4.2.2 "I was doing it all along", and still do

Just two teachers (G1 and K1) said they have not made any changes as a direct result of the appearance of HSW as a curriculum element, and did not waver from that answer. The two representatives in this small "doing-already" group were, however, very different.

One is characterised by a statement which teachers in other groups have also articulated:

> "New syllabuses come and go, material comes into the syllabus, material goes out of the syllabus, you know, they switch it around, and put it in like this, and then they move it around and take it out like that. Nothing *really* changes. Nothing changes." (G1, 95-97)

Other teachers, however, tended to qualify a bold statement like this by adding that they did make changes to their teaching when the syllabus was changed (see section 4.2.3). In the case of Teacher G1, who taught physics at a selective school, his conviction that there was no need for him to change seemed as much a recognition of the potential of HSW in older curricula as confidence in his own interpretation of HSW as it became. This was exemplified by his view of the use of practical work to let pupils determine whether the teacher has told the truth about a piece of scientific content knowledge. He felt that "to some extent, the experimental side of things has always been like that" (50-51).

Teacher G1 expressed firm ideas about some of the other aspects of HSW, namely that he used the history and philosophy of science and the applications and implications of science anecdotally, and felt that good teachers would have been doing that from the word go, developing their range and repertoire as they got more experienced.

The other teacher in this "doing-already" group is Teacher K1, who taught biology at a Sixth Form College. He has shown creativity with how new research and ideas are implemented, and has not felt threatened by the appearance of HSW in the subject criteria for biology at A-level: "[HSW] wasn't anything that I would say was alien in any respect. I think it's always been there, I think they were just trying to highlight its importance a bit more" (69-70). When considering the statements of HSW in the curriculum, he said: "I think they're useful, and they're beneficial, and they're important, which is why I did them in the first place, I think" (213-214). This does not mean that K1 has not changed. On the contrary – he has been working hard to help his students to understand the importance of the new 'Suggest' questions (see below, with Figure 4.1) in up-coming exams, "giving students more exposure, if you like. That's something I think I *have* increased through... partly through [an Assessment for Learning-related] project, but partly through [HSW] as well" (93-94). K1 also had something to say about what good teaching is: "I think it's something a good teacher would do in teaching science, is the applications, and the uses, and the relevance, and developing important analytical and research skills, and so on" (13-15). As he homed in on the explicit teaching of applications and uses, he seemed to have prioritised rather differently from Teacher G1 who would only use this aspect of science anecdotally.

'Suggest' questions have been introduced into A-level exams recently. There usually are more correct answers than the question asks for, and the mark scheme is written accordingly (see Figure 4.1). An example of a 'Suggest' question is question 5b from the OCR Biology paper for the module 'Cells, Exchange and Transport' for June 2011, which reads: "Suggest **two** factors that should be considered when carrying out a risk assessment for an experiment using a spirometer" (Oxford Cambridge and RSA Examinations, 2011, p. 11).

5	(b)			**Mark the first *two* factors.**
		1 check health of volunteer ;		1 e.g. check medical history of volunteer ask about asthma / TB / pneumonia / flu / bronchitis / emphysema
		2 oxygen used ;		
		3 new / sterilised / disinfected , mouthpiece (for each volunteer);		3 **IGNORE** clean mouthpiece
		4 *idea of:* soda lime working ;		4 **CREDIT** need to remove CO_2 / CO_2 accumulates
		5 sufficient oxygen in chamber ;		5 **IGNORE** enough air in chamber
		6 water level not too high / water must not enter tubes ;		6 **IGNORE** general ref to leaks
		7 ensure valves working correctly ;	**max 2**	

Figure 4.1. Mark scheme for question 5b of the June 2011 OCR Biology paper for module 'Cells, Exchange and Transport' (Oxford Cambridge and RSA Examinations, 2011, p. 12)

Some of the sentiments presented by these two teachers were also recognised among the other groups, especially the position that good teachers will have been teaching certain aspects of HSW as a matter of course (e.g. Teacher C1, see section 4.2.1, and Teacher E3, see section 4.2.3), and that it was nothing to be afraid of (e.g. Teacher J2, see section 4.2.3).

Teacher K1 felt that any and all of the aspects of HSW were things a good teacher should have been 'doing' before, and that he had been doing them all along because he had always felt that they were important. He was happy to incorporate new ideas into his teaching, but felt that there had not been anything he could pin down to HSW specifically. Because it was easy to appreciate, from our interview and the observations made, that he had indeed incorporated many aspects of HSW into his teaching, in various creative ways, before 2008, he should be classified as a 'pioneer'.

As Teacher G1 felt that the curriculum change had not been a real change at all, and that his teaching approach fitted just as it had done before, that his pupils were getting a good deal and good results, and that there had been no need for any drastic changes, he is a 'confident veteran', although some might say he is as cynical as he is confident, and he used the word 'cynical' himself in our interview. As he is positive about the content of the HSW section of the curriculum itself, he deserves a positive label. When describing his readiness to change he must be given a position on the border between 'pioneering' and 'embracing', because he was ever ready to incorporate changes as they were required, and felt he had always dealt with HSW appropriately, even before it was given emphasis in the curriculum.

4.2.3 "We were doing some of it already", but...

Half the teachers (namely A2, D2, E3, F3, G2, I1, I2, I3 and J2) said they had made some changes although they claimed that they would have been doing some or all of what is now under HSW in the NC before its increased emphasis in 2006. They tended to do this by referring to 'we' as much as 'I', as they seemed to feel it ought to be quite obvious that a good teacher does what is required for HSW. For example, Teacher G2 said: "For myself I wouldn't have said that was any more than what we were doing before; it just didn't have a label on it" (39-40). Despite this, all teachers in this group acknowledged quite readily that they *had* made changes to their teaching in response to the curriculum change.

In a sense, the teachers in this group can all be considered pioneers, as they say they were teaching HSW before they had to. As Teacher I1 proffered:

> "In chemistry, for, ooh... 7/8 years we've probably been introducing many of the practical skills, so ok, not everything on the HSW agenda, for want of a better word, but the practical elements, we've been introducing as a sort of a Key Skills type topic." (I1, 252-254)

But even for these teachers there is a spectrum of readiness to make any changes deemed to be required. Some were embracing the changes immediately upon HSW's increased emphasis, while others took longer in following.

Teacher F3, for instance, described the move away from strict adherence to the investigative side of what used to be Sc1 to a broader interpretation of ideas-about-science upon the appearance of HSW in the NC:

> "I think to begin with it was much more just about carrying out a practical, if you like, and being able to carry out an investigation, and now it's more about the wider aspects of peer review and the way that scientific theories develop, rather than just investigating a practical yourself." (F3, 18-20)

One aspect of HSW to which many teachers referred, is the increased use of discussion and debate in science lessons. Some departments relied on new members of staff to refresh and expand other teachers' expertise, as Teacher I1 explained: "we've always had discussions and debates, and arguments; as staff have changed, in the department, we've seen different approaches come in, which has strengthened some of the work we've done" (332-335). Teacher I1 is of the 'following' type in this respect, although he has been more proactive in other areas (see above, about the practical skills part of the HSW agenda). He commented on the continuity of the teaching of 'skills' related to HSW compared to earlier curricula, but by the same token his and his colleagues' needs to strengthen their understanding of the requirements.

Some departments held off changing their schemes of work for a while, as they felt HSW was introduced too quickly so they persisted with the older version of the NC as long as that was allowed. As Teacher E3 put it, regarding their delaying it for KS3:

> "You didn't have to put it in that first year; it was brought in so late, that you couldn't actually change the whole of your KS3 to do it, so ours the first it would have been taught to Year 7 in 2009 [sic]." (E3, 29-30)

As for KS4:

> "We had to incorporate the HSW lessons in there slightly before that, but again it was introduced very quickly, for putting into your schemes, so it tended to be taught in bolt-on packs at the end, rather than, as it's now, the integral one." (E3, 35-37)

Similarly to the other two groups, the teachers in the "doing-some-already-but" group expressed their thoughts about HSW in terms of good teaching and there having been no need to be afraid of the change. For example, Teacher E3 pointed out that it fitted with her teaching as it was before, with adaptations and renewed emphasis, which she expressed as follows:

> "To be honest, I think it was already there anyway, it's just become more sort of pointed out than it was before. Any good teacher who was trying to teach theory had a practical application anyway, because it brings it home, doesn't it? It makes it a reality." (E3, 10-11)

Likewise Teacher J2 was confident his teaching was up to the requirements of HSW and therefore he had had nothing to fear of the changes, as he said:

> "When I was told about it, it didn't actually worry me as much as it seemed to worry others, it didn't seem anything that new, because it just seemed like these are the type of things that come up during the course of teaching science" (J2, 30-32)

The teachers in this "doing-some-already-but" group can be assigned on the spectrum as follows, based on evidence which was typical for their position and represented the overall impression they gave in our interviews (and observation, if performed):

- A2, who was not in the same department as A1 in 2006, was not a fervent supporter of the change from the beginning, as he acknowledged it was a case of "I just remember it kind of phasing itself in, really" (15). He should therefore be classified as the 'following' type.
- D2, who joined D1's department some time after 2006, "first heard about it through the Exploring Science course that was brought in around 2007ish; [he] taught it at [his] old school as part of the new KS3 within science" (6-7). He acknowledged that he did not "know what year it was officially introduced" (323) but, when told that it was meant to be introduced into KS4 in 2006, said: "That makes sense, so I guess when it comes in in terms of that – in 2006 I had been teaching for 4 years so I'm probably changing what I am doing anyway, we change how we do things all the time" (331-332). He seems to have responded to the change as required, but not necessarily immediately, so should be classified as 'following'.
- E3 has been 'following' as late as possible, as exemplified in a number of quotes presented above.
- F3 was ready to take on any changes as he saw the need for, as he was prepared for the change from the very beginning, through "the NC documents that [he was] passed, and from various courses that [he]'d been sent on" (6-7). He should therefore be classified as 'embracing'.
- G2 made the impression of being very compliant, following the textbooks and schemes of work as best she could, as she said, holding a course specification document in hand as we talked: "line by line, topic by topic, it's given me examples where I possibly could bring in one of those concepts, bring in one of

those theories, bring in one of those skills" (436-437). As she started doing this as soon as the paperwork reached her, she should be classified as 'embracing'.

- I1 is difficult to classify into one single category, as he presented himself so clearly differently with respect to at least two different but important aspects of HSW (see above). He was 'pioneering' in the teaching of 'skills' related to investigation and enquiry, but only 'following' when discussion and debate were concerned. On balance, he fits best on the border between 'embracing' and 'following'.
- I2 seemed in two minds, both about HSW as a whole and about specific aspects of it, as he said "the longer it's been since 2004 the more [he] think[s] it's a good thing" (15-16), while he also enthused about Salters' Nuffield Advanced Biology (SNAB), in that he "think[s] [his] own development went in parallel with SNAB because SNAB, to [him], does HSW as it should be done which is just you don't even know you're doing it" (94-96). The first quote might imply that he was quite reluctant at first to include (certain aspects of) HSW in his teaching – and he was particularly scathing about the assessment of the investigative side of it through ISAs (Investigative Skills Assignment, see section 4.3.7.2) – whereas the second quote would imply he was pioneering it from the early days of SNAB. None of the single categories sits comfortably for I2. On balance, he fits best on the border between 'following' and 'reluctant'.
- I3 has been dependent on paperwork and discussions with colleagues from the start, implementing HSW into his teaching as he went along by "shall we say, in the early days, being half a page [of the textbook] ahead of the children" (46-47). As he always made sure he was ready, he should be classified as 'embracing'.
- J2 seemed totally calm about any change he felt that was required for him to teach HSW appropriately, and was fully ready for it. He said: "the thing that I thought 'oh maybe we need to actually do as part of a lesson', was 'thinking about the overall view of the scientific process', but to be honest that was something anyway that we might well have gone through" (45-48). He should be classified as 'embracing'.

4.2.4 'The spectrum of readiness to change'

The spectrum as has been introduced in the previous sections will be named 'the spectrum of readiness to change'. The ideas for the spectrum developed directly from the data. Although similar frameworks can be found in the literature for different areas of research in education, psychology and beyond, none of those frameworks covers the data as well as the proposed spectrum and it must therefore be seen as new. This will be discussed further in chapter 9.

The other categorisation of the teachers, into groups of "doing already", "changes-certainly" and "doing-some-already-but", overlaps the spectrum of readiness to change fully. All teachers considered in this chapter so far, i.e. the ones who had been science teachers before the curriculum changed, have a position in both frameworks. Within each of the three change groupings, however, there is scope for an individual to have approached that change in any of the ways the spectrum of readiness to change allows. Some of the teachers acknowledged that their attitude towards the change had shifted since the introduction of the new curriculum. Teacher I2, for example, had been quite reluctant at first, becoming more enthusiastic with time. Others were not uniform in their attitudes towards all aspects of the new curriculum, e.g. teacher G1 who was adamant there was no need to include the history of science other than anecdotally, without jeopardising the benefits of HSW to pupils, and while maintaining that he had been teaching all that was required for HSW even before it was introduced as a curriculum element.

The reluctance or even subversion that can be sensed in some of the teachers' responses leads to a consideration of the need for an extension of the spectrum towards the more negative, through alternative outlooks to the ones discussed so far.

4.2.5 Alternative outlooks

All 25 teachers generally had a positive outlook on the emphasis of HSW in the curriculum at present (see also section 7.2), and have incorporated the required elements into their teaching since 2006, if they had not done so already. There was no overwhelming sense of reluctance, let alone subversion, in any of them, which might have been anticipated as potential alternative outlooks in a study like this. In fact, Ryder and Banner (2013) did encounter a certain amount of reluctance in some of their participants, as one of them remarked that they "do still have some staff who are reluctant to change" (p. 14). The authors explained this reluctance by referring to teachers' "experience of the 'education pendulum'" (p. 22). Teacher G1 also referred to something akin to this pendulum, but did not display the weariness that Ryder and Banner sensed alongside, which they encountered in their reluctant participants. Of the other teachers in the present study Teacher E3 was the most vocal in her defence of delaying the introduction of changes to the schemes of work in her school (see section 4.2.3), and therefore perhaps closest to being a 'reluctant' participant. However she was generally positive about HSW in the curriculum, and therefore fits as a 'following' participant in her group.

Ryder acknowledged that the term 'pioneer' might be preferable over the term 'frontier teacher' as they used in one of their articles (Ryder, pers. comm.).

Now teachers' reflections on the changes to their practice have been explored, in the next section follows an examination of what teachers said their current practice actually entails. In this, terms such as 'skill' come to the fore alongside the emphasis on the specific elements of HSW in the curriculum.

4.3 Teachers' current practice

4.3.1 Teachers' spontaneous commitment to different aspects of HSW

When teachers were asked to briefly describe the main thrust of HSW in the curriculum, a wide range of possible answers resulted. These are presented in Figure 4.2 and discussed briefly below. History and philosophy of science (HPS) is further abbreviated to H, I stands for Investigation (i.e. the practical and investigative aspects), and S is the abbreviation for Socio-scientific aspects.

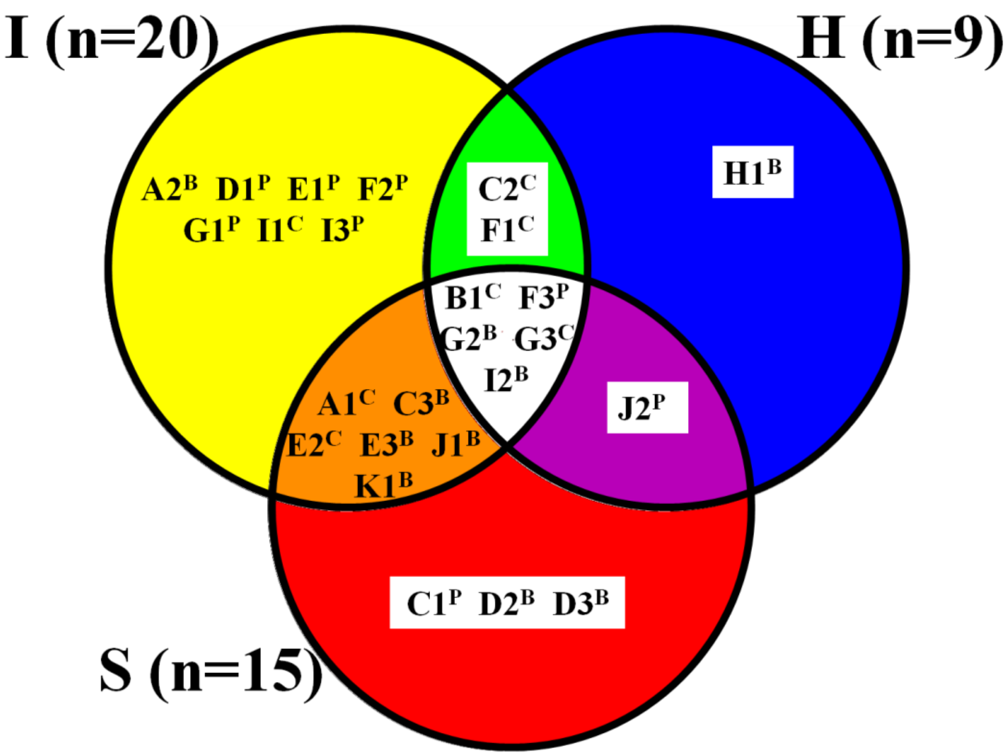

Figure 4.2. Teachers' descriptions of the main elements of HSW in the National Curriculum (overall n=25); H = History and Philosophy of Science, I = Investigation, S = Socio-scientific aspects. Superscripts indicate subject specialism: B = Biology, C = Chemistry, P = Physics

The largest group, seven teachers, saw HSW in terms of scientific investigation only. For example:

> "Identifying variables, planning investigations, making measurements, collecting precise and reliable measurements, analysing that data, different methods of displaying that information, using it to draw conclusions, are those conclusions valid?" (I1, 62-64)

A more extensive commentary on classroom practice in which there is an emphasis on investigative skills follows in section 4.3.3.

A minority focussed particularly on the importance of the socio-scientific implications and applications of science. These were:

> "What it really means to me is just putting the science in the context, making it realistic, which in turn makes the learning improve and makes it more fun generally I think. So to me it's context leading to it being much more interesting and involving."(C1, 67-69),

> "I think it's the application of science, so trying to help students to see the real applications of the things that they are trying to learn, so how it would fit."(D2, 16-17)

and

> "applications, so putting it into context, is how I see HSW."(D3, 32-33).

Classroom practice with an emphasis on socio-scientific issues is discussed further in section 4.3.5.

Only one teacher saw HSW exclusively in terms of the development of scientific knowledge and other historical and philosophical aspects: "I guess we are always teaching it towards exams, I will be honest, so data, evidence, theories, explanations much more than communication skills, that is I would say how we work it" (H1, 38-39). Further discussion of an emphasis on HPS in classroom practice follows in section 4.3.4.

While the teachers mentioned so far in this section concentrated on one particular element of HSW in the initial stages of our interviews, this does not mean that these teachers focussed exclusively on these elements in their teaching (see for example section 4.3.4), nor does it mean that they did not go on to discuss the other elements during our interviews.

In addition to the group of teachers who focussed on one of the three main elements of HSW, just over half the teachers mentioned a combination of the three elements which, apart from in the case of Teacher J2, always included practical and investigative aspects. All of the chemistry specialists fell into this latter category – acknowledging investigation as an important aspect of HSW – which is unsurprising as it must seem all but impossible to teach chemistry without some practical aspects. Some of the teachers did acknowledge that, at some stage in the past when HSW was new in the curriculum, they might have equated HSW with investigations, to the exclusion of the other elements which they now included. This was most eloquently put by Teacher F3 (see section 4.2.3), but also clearly recognised by others, for example:

> "At first I think it was quite narrow, just thinking about the practical, and then it's expanded now, definitely, into looking at wider implications… more use of models… looking at real life scenarios, and ethics and things… so it's a lot wider." (C3, 35-37)

This association may stem from an initial identification of HSW with attainment target AT1 or Sc1 as it was in the previous versions of the NC, which for a time was mainly or even solely concerned with scientific investigations. The move away from that limited view was obvious, even for a teacher who still feels investigation is a major part of HSW and science teaching:

> "In going back to the old specification, it feels like a very long time ago now, we worked on skills, we worked on the old Sc1 but that felt very much about doing a practical and writing it up, it wasn't about science as a whole and I think now we apply those ideas about questioning and evidence and communication skills across the board." (D1, 93-96)

Now that the six features which will be discussed more deeply in their respective sub-sections (4.3.3-4.3.8) have been introduced, it is appropriate to briefly present teachers' current practice as displayed through the observed lessons.

4.3.2 The observed lessons

The eleven observed lessons provide a sample of current practice, of the elements of HSW as teachers display in the course of their teaching (see Table 4.1). As the observations were only performed with a subset of interviewees and were not intended to provide additional data for analysis, they are only briefly described here to provide a flavour of what, if anything, might be seen of HSW in lessons.

Only the HSW elements clearly connected to the main thrust of the lesson are included in this table, while most of the teachers also displayed the other elements in a more minor way. For a more extensive overview of the observed lessons, see appendix D.

Teacher	**'HIS' grouping as declared during interview**	**'HIS' elements as displayed in observed lesson**
B1	HIS	S, and communication
C1	S	S, and communication
C2	HI	H (evidence), and communication
C3	IS	I, and communication
D1	I	I, and communication
D2	S	I
E2	IS	IS, and communication
G1	I	H (anecdotal), and communication
H1	H	I, and communication
I1	I	H (anecdotal), I
K1	IS	HI, and communication

Table 4.1. 'HIS' commitment, self-reported during interview, and displayed during observed lesson

The 'HIS' elements displayed in the lessons do not necessarily match those declared as important in the initial stages of our interviews, as not all lessons in all topics lend themselves equally well to the teaching of all the elements of HSW, and the teachers will have chosen the elements they thought most appropriate to the learning objectives. Moreover, as mentioned before in section 4.3.1, most teachers acknowledged later on in our interviews that other elements of HSW, other than the ones instinctively mentioned initially, were also part of their classroom repertoire. Rather than show or prove a match between teachers' initial commitment to certain HSW elements during interview and their actual teaching of those elements during the observed lessons, Table 4.1 gives a feel for the variety of HSW teaching observed.

As can be seen from Table 4.1, communication skills were an important part of the lessons observed. In fact, *verbal* communication *between* pupils was also an important part of the lessons which have not been assigned this label. 'Communication' was only added as a label for lessons in which more specific scientific communication skills were addressed, such as 'using quantitative approaches' (lesson G1), or 'present information, develop an argument and draw a conclusion, using scientific language and ICT tools' (lesson B1).

A notable feature of all observed lessons was that the elements as they were addressed were not explicitly linked to scientists' activities, HSW or lesson objectives (if the latter were declared to pupils). 'Peer review', for instance, as used by Teacher B1, was not announced in any formal way. The pupils were given a grade level ladder to help them review other groups' videos. The level ladder set out requirements for levels 4, 5 and 6. The pupils knew what to do with the information on this level ladder without being explicitly told what was required of them. The training in the use of the skills involved must either have been explicitly taking place in earlier lessons, or happening through more implicit means.

4.3.3 Emphasis on practical work and investigation

Teachers who identified investigation as the most important aspect of HSW (i.e. A2, D1, E1, F2, G1, I1 and I3) talked about the skills and processes involved in the practical side of science. For instance:

> "Whether we're doing the simplest experiment of just counting, or with something more complicated at A-level, it's numerical skills, to be able, for example, even at a basic level, to do your experiment once, to do repeats, to do an average, to spot anomalies, then take that a bit further, maybe, for example, to plot a graph." (I3, 137-140)

They used the word 'skill' fairly broadly (see also section 4.3.6), as do many other people when they talk about skills (Wellington, 1989). They sometimes dedicated whole lessons or series of lessons to develop the skills as they saw them as needed for carrying out investigations.

Some teachers managed to find time to let their pupils choose and run their own individual investigations, for example in order to qualify for CREST awards (British Science Association, 2012), as in the observed lesson with Teacher D1 and one of her Year 10 classes. This was clearly a lesson in which the objectives were all about HSW:

> "There is no overall knowledge statement because they are all doing different things. So I think the most that I could put on the board of the knowledge statement is 'learn something new about your chosen topic'. So it's all about 'develop your skills', be they about research or presentation or communication, whichever." (D1, 249-252)

More commonly the investigative process is more structured and more limited in nature, with teachers choosing the scope of investigations – even D1's colleagues "have given them a theme or [...] what some groups have been doing has been a little bit more focused" (66-67). This is often done with the assessment of investigative skills through the KS4 and KS5 ISAs used by the Assessment and Qualifications Alliance (AQA) in mind, as Teacher E1 said: "obviously quite focussed on the ISAs in AQA, so a lot of the information that I have about HSW is geared towards prepping them for the ISAs" (7-8). ISAs, the Investigative Skills Assignments, were in the process of being replaced by other assessment models but teachers continued to concentrate on assessment requirements. This is true for other exam systems too. For a more extensive commentary on assessment of investigative aspects of science, including a brief explanation of ISAs, see section 4.3.7.

A quarter of the teachers referred to Sc1, as it was presented in previous versions of the curriculum, and some used it to justify their emphasis on investigation. Teacher G1 recalled: "if you think back to quite a few years now, the NC at KS3 being given Sc1, 2, 3 and 4, and Sc1 is the HSW, well, it was grouped together at that stage, when that first appeared" (120-122). Although he acknowledged that Sc1 did not really include much, if anything, about aspects such as 'theories' and 'applications', he was confident that his interpretation of the curriculum withstood the test of time, as he said "the way that we teach isn't affected by a change in the grouping of the terms, because we've always grouped them together in a way which we think is best anyway" (132-134).

More than three-quarters of the teachers mentioned the importance of evidence at some stage during our interviews, and quite often this evidence would have been related to investigations, namely the obtaining, analysing and evaluating of evidence in experimental science. Evidence and the critical evaluation of information is, however, more generally seen as important when learning science, and many of the teachers use the media (e.g. Science in the News, NHS Behind the Headlines (National Health

Service, 2007-2012), and Bad Science (Goldacre, 2000-2012)) as a resource to make their pupils appreciate this importance. For example:

> "I think if we can get across that whole spirit of inquiry because you know the media – and it comes back to this whole critical thinking about the media – some elements of the media would have you believe that everything, even these new discoveries and research, is fact but actually what they forget is that whole idea of enquiry." (I2, 514-518)

Teacher A2 similarly stressed the importance of critical appraisal of information in the media, as he said:

> "There are loads of newspaper articles about everything going related to science, and everyone's got their opinion, and quite extreme opinions in some cases, and I think it's important that they need to be able to make sensible, sound, decisions based on scientific information that they know and based on an understanding of science about these [socio-scientific] kind of things, rather than knee-jerk reactions." (A2, 477-481)

Many teachers, especially those who taught AQA GCSE courses, mentioned the need for specific and explicit teaching of the terminology involved with investigations, and the boundless confusion this raises among staff and pupils when changes are made to specifications:

> "We had a big fuss about terms like accuracy, precision, reliability, reproducibility, repeatability – all this! And we are all confused! And you sometimes feel on some of that, does the language matter as much as actually that the kids can tell 'is my result close to what it should be?' Actually once you have got to grips with the language it is a good thing, it is just the language that has been getting in the way." (F1, 457-461)

These terms predate the HSW curriculum, and the confusion has been reported before, which is why the Association for Science Education and the Nuffield Foundation jointly published 'The Language of Measurement' (Campbell, 2010). Teachers sometimes spend whole lessons specifically on terminology, usually resorting to traditional teaching methods to get it across effectively, as Teacher A1 explained: "I do tend to go through a standard chalk and talk for showing them how to set out a graph, and also for looking at changing variables. That seems to be something they still struggle with" (307-309). A PowerPoint presentation is in circulation, for example as part of the resources provided by AQA over the years, with images of dartboards which some teachers use to instil an understanding of the difference between accuracy and precision (see Figure 4.3).

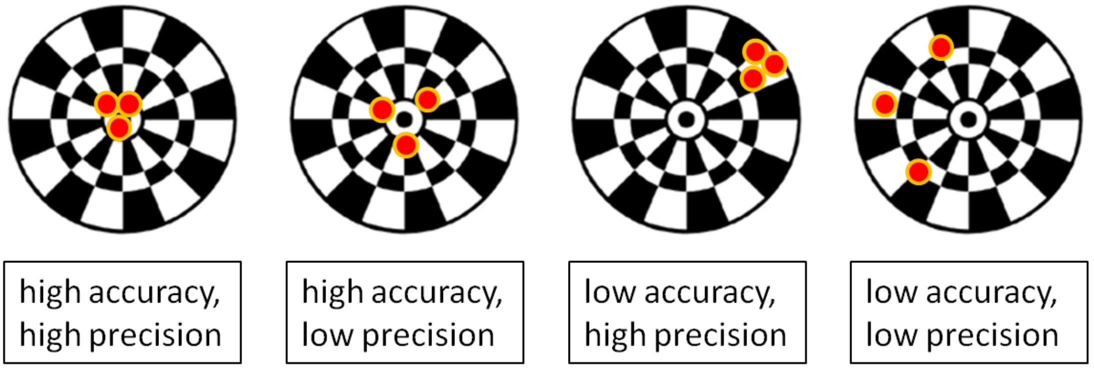

Figure 4.3. Dartboard (target) analogy for teaching accuracy and precision. Reproduced from memory, guided by online examples.

As referred to by Teachers I3 and A1 already, the development of certain mathematical skills, such as calculating averages and drawing and interpreting graphs, is another area of HSW on which some teachers are prepared to spend whole lessons. Teacher C3 confirmed:

> "In fact, we run a whole week, at the beginning of our A-level course, a HSW week, where they just do all those things. We have a graph skills lesson, we have… I can't remember all the different lessons that they do, but they have a full week where all they do is HSW." (C3, 190-193)

Sometimes teachers will go as far as using artificial data in order to get a certain point across unequivocally, although real data from pupils' own experiments are also commonly used to develop mathematical skills specifically.

This section presented teachers' reflections on 'investigation', such as:

- the opportunities for their pupils to acquire skills and understand the processes they perceive as needed when investigating scientifically, such as an appreciation of the importance and nature of evidence, and the terminology and mathematics involved;
- the links between 'investigation' as part of HSW on the one hand and Sc1 from earlier versions of the NC on the other;
- the opportunity to include learning objectives which do not contain any scientific content knowledge, and to focus in lessons on skills development and other aspects of HSW only;

- the freedom, and sometimes lack thereof, to let pupils choose their own topic of investigation.

4.3.4 Emphasis on history and philosophy of science (HPS)

The history and philosophy of science, e.g. the development of scientific knowledge through the understanding of theories, ideas and models, were brought up as an important part of science teaching and learning by some teachers because they feel it should give people an understanding of the *limitations* of science as well as its possibilities. In addition, for many of them science is not a body of facts to be learnt. This was put in the form of a mission statement by one teacher:

> "Well to me what I fundamentally want to get over to every single person in the country is the idea that science is not fact, it is just these are the best theories we have from what people have come up with, with the evidence that we have." (F1, 505-507)

Teaching pupils about the limitations of science is not always easy, as newly qualified teacher (NQT) F2 found when she was teaching about the Big Bang and pupils asked her "'well, what happened before that?'" (574). She had explained to her pupils that she simply does not know, and recounted:

> "They really don't like that at all [...]. But I think that again is important because they will ask questions and they will look at you as if to say 'well why don't you know?' and you think 'well it's not just me that doesn't know, it's everyone doesn't know, so don't judge me!'" (578-582)

Some teachers, however, see the development of theories through history more as background reading and anecdotes than as something that has to be taught explicitly (see also section 4.2.2). For example, Teacher I3 said "every textbook has had a bit of it, but it's never been called HSW, it's just been background reading, or it's just been an introduction to the topic" (215-217).

A much more explicit and active way of teaching about the development of an understanding of the history of present-day theories is through research of the scientists involved in the various stages of the development of those theories. Pupils may be asked to play the roles of each scientist in a debate about the relative merits of each part of a theory, or to present evidence for these merits in some other way, through posters for instance. This activity is included in the Support Pack for the Salters' Advanced

Chemistry course (Denby, Otter, & Stephenson, 2008). Although this particular activity was not mentioned by any of the teachers directly, the concept of a mini-conference where everybody presents their own piece of research did occur in Teacher J1's repertoire (see section 4.2.1). The subject of the Salters' activity, namely the development of the atomic theory and the model of the atom, did feature highly in teachers' minds when they started thinking about how they use the history of science: a quarter of the teachers used it as an example.

Some teachers referred to the presence of what was colloquially called 'Sc0' in some earlier versions of the NC, or 'Ideas and Evidence' as it was called in the version immediately preceding the present one. Teacher F1's position regarding Sc0 and its successes and failures in the development towards what is now HSW was already presented in section 4.2.1. 'Ideas and Evidence' was the section next to 'Investigative skills' as part of Sc1 'Scientific enquiry' in the NC in 1999 (DfEE & QCA, 1999). It included four statements which covered historical, philosophical and socio-scientific aspects, reminiscent of parts 1 and 4 of HSW in the current NC for KS4. Teacher D2 used the phrase fluently in conversation, namely that he "always [tries] and talk[s] to [pupils] about *ideas and evidence*" (99-100, emphasis added). He trained as a teacher when the 1999 NC was current, and it is likely the phrase stuck with him. Teacher D2 did not refer to any training specifically, unlike Pilot Study Teacher T3 who was convinced that her 'Ideas and Evidence' training had prepared her particularly well for the requirements of the curriculum change for 2006.

The importance of evidence was often stressed when teachers referred to aspects of HPS, and the news media were, as mentioned before in section 4.3.3, often used in activities designed to instil this into their pupils. Pupils were taught explicitly what to look for in an article: e.g. reference to real scientists by name and affiliation, sample size ("What is your sample size, if you sample 100 people can you apply that over the country?", J1, 468-469)), statistics used in an appropriate way ("When people are writing, they have an agenda often, and they're trying to trick you into agreeing with them", B1, 572-574), variety of research ("Has it been backed up by any other scientists?", F2, 247-248), and appropriate use of literature.

The role of models, both pupils creating them themselves and the evaluation and explanation of existing ones, was seen by over half of the teachers as important in the development of an appreciation of what scientific theories can tell us. One of the NQTs, Teacher G3, acknowledged that the role of models was stressed to her in her teacher training course, where "modelling was a really big one for [the trainees], because you know, science might be boring in lessons or whatever, so the modelling thing was drilled into [them]" (17-18). Teacher C2, recently qualified from a different course, also talked about modelling with great enthusiasm but in her case it was not because of anything in particular from her training.

Only one teacher, namely Teacher H1, posed 'data, evidence, theories and explanations' as the most important part of HSW in the early stage of our interview, especially relative to 'communication skills', without mentioning the other two. Interestingly, her lesson was possibly the nearest to what could be considered part of an investigation, as her year 9 pupils were in the process of planning an investigation into osmosis in potato samples. So for Teacher H1 HPS most certainly was not the only important aspect of HSW (compare Figure 4.2). Although she stated in our interview that communication skills were not a high priority in her department, detailed attention was paid to naming different variables (independent, dependent, control), terminology (reliability, precision, specific equipment and procedures) and Health and Safety, and the appropriate way to write up all this information in the course of a scientific investigation.

In summary this section about what is essentially part 1 of HSW of the KS4 NC communicated teachers' thoughts about the limitations of science, and that science is not a body of facts; whether this aspect of HSW can be taught implicitly through anecdotes, or whether it needs more explicit activity; the links with earlier versions of the NC where similar sections were called 'Sc0' or 'Ideas and Evidence' at different times; the merits of evidence and how pupils may learn to fathom reports of science in the news; and the importance of scientific models.

4.3.5 Emphasis on socio-scientific aspects

Although very few teachers mentioned socio-scientific aspects of HSW first when asked about the main element(s) of HSW, this is where most individuality and creativity was displayed. For example, in two of the observed lessons pupils were set to produce work in various forms, namely magazine articles in Teacher C1' lesson (for a fictitious magazine, but potential readership and other factors were discussed so that writing was fit for purpose) and video in Teacher B1's lesson, with role play and drama actively encouraged in the latter. Teacher D2, like Teacher J1 (see also section 4.3.4), told how he has made his pupils appreciate the importance and use of peer review through organising a mini-conference in which all pupils researched a small part of a topic (commonly from research articles), and presented a poster which they then explained and defended to their peers.

The use of science in the media was stressed, as before in the teaching of HPS and the use of evidence in investigations. Teachers talked about keeping an eye on the news and pupils bringing in news stories, and one teacher was disappointed at a missed opportunity to link an important news story to what went on in lessons with the socio-scientific aspects of HSW, as he explained:

> "I guess there are other things, ethical questions, roll in Society, I felt I missed a big opportunity this year actually with all the Fukushima stuff that was going on because we were actually looking at radioactivity there and I felt maybe I should have responded quicker to what was going on in the news because that would have been fantastic really to get that context in."
> (J2, 83-86)

Others talked about their successful use of science in the news, for example Teacher C2 who said she and her pupils had been "looking at more things like the ethical things, we always do things like Science in the News about something like animal testing" (230-231). Another was not so optimistic about pupils learning to understand science in the news in school science lessons, as "we focus on quite a narrow way of looking at it, and some of the arguments are very sophisticated; they don't have the knowledge base to cope with that, and then they can't apply it in other situations" (E2, 771-776). She hinted here at something others have picked up on as well: the focus *can* be narrow, because the assessment of socio-scientific aspects of HSW in examinations is often also narrow (see sections 4.3.7 and 4.3.9). She also referred to the requirement of high-level thinking and lack of scientific content knowledge limiting pupils' success in this aspect of HSW learning, which is discussed further in section 6.4.4.

The human aspect of science, e.g. scientists as humans and the scientific community consisting of humans, turns out to be important to both teachers and pupils. Teacher I2 exemplified this:

> "I try and bring in, especially at A-level, characters in science; so I'll talk about the individual scientists and pull up some, you know, often it's some American guy and you can get a picture of him holding a surf board and add a bit of fun with it and talk about the human element of these people, which I think the students like." (I2, 328-331)

Teacher J1 suggested it when he said "I like [HSW] because I like the human nature of the HSW in terms of particularly benefits, ethical issues, I like that aspect of it" (483-484). When asked what HSW might mean to his pupils, he added that "some people only come alive when you have got that element of HSW which is the benefits, ethical issues, that kind of re-ignites the theories" (619-620).

The teachers said that ethical issues are most often taught and learnt through discussions and debates, directly or with role play, sometimes by making pupils "argue a case that they don't necessarily believe personally in" (I2, 346-347), although some teachers claimed that examination questions about ethical issues are so predictable that rote learning is an option and explicit teaching is unnecessary (see sections 4.3.7. and 4.3.9). This means that their pupils may have less experience of debates, discussions and argumentation than those with teachers who do run those activities.

In summary, this section revealed teachers' thoughts about the human nature of HSW, and a variety of classroom activity related to the socio-scientific aspects of it. Teachers spoke about the need for discussions and debates, and an understanding of ethics and peer review, although not all agreed about the need for explicit teaching of some of those aspects.

The previous three sub-sections were concerned with the emphasis on the three main sub-sections of HSW, namely 'HPS' (H), 'investigation' (I) and 'socio-scientific aspects' (S), with a few brief reports of teachers' practice concerning 'communication'. Besides those clearly delineated sub-sections as they are in the NC for KS4, there are a few other aspects to HSW teaching which were so prominent in the interviews, that they each deserve a separate section: skills (4.3.6), assessment (4.3.7) and textbooks (4.3.8).

4.3.6 Emphasis on skills

The words 'skill' and/or 'skills' were employed by all but one of the teachers. There are some problems with this, as Hunt noted in his report for SCORE:

> "An unsatisfactory feature of this version of the National Curriculum, which is still current, is that the knowledge and understanding needed to carry out and interpret investigations comes under the heading 'skills', a term generally perceived as something that develops with lots of practice." (Hunt, 2011, p. 2)

Arguably there are a lot of well-defined skills involved in the 'carrying out and interpretation of investigations', but the 'knowledge and understanding' required most certainly cannot be developed simply through practice. If teachers do not appreciate this distinction, making assumptions about how pupils learn to carry out and interpret investigations, some of the intended outcomes of HSW would be lost.

Figure 4.4 shows how frequently the words 'skill' and 'skills' were used per teacher.

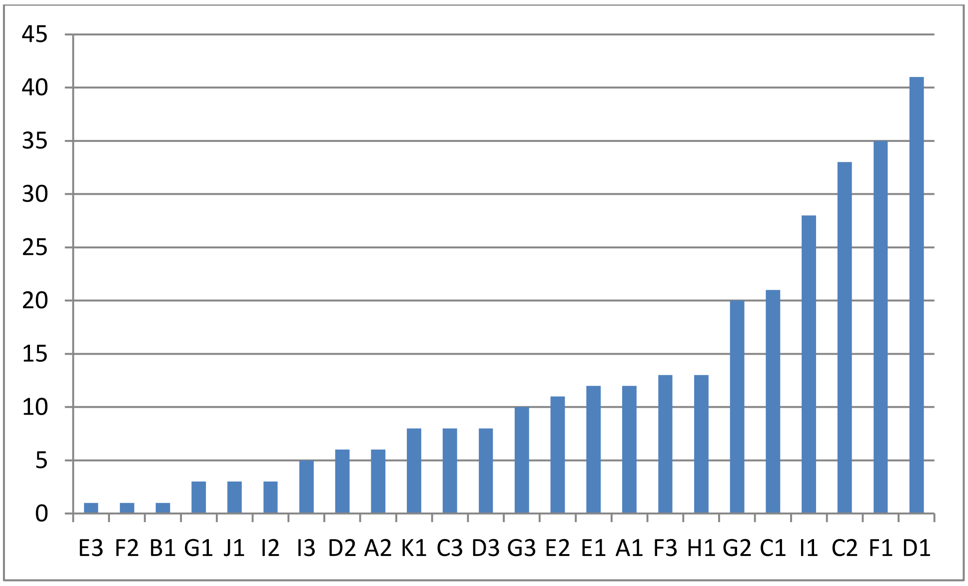

Figure 4.4. Frequency of use of the words 'skill' and 'skills', by teacher (n=24)

At least one feature is of note, which is that Teachers F1 and D1 were subject leaders in the same local authority and they had regular subject leaders' meetings with their local education consultant. Teacher I1, who was subject leader at an independent school in the same authority area, also attended these meetings, but not as regularly.

The UK Skills Agenda was given prominence with the national Skills Strategy as set out in the '21st Century Skills: Realising Our Potential White Paper' (DfES, DTI, HMTreasury, & DWP, 2003). The aims of the strategy are clear:

> "The aim of this national Skills Strategy is to ensure that employers have the right skills to support the success of their businesses, and individuals have the skills they need to be both employable and personally fulfilled." (p. 11)

Unfortunately, the definition of 'skill' used is not nearly so clear, although a list is given in the summary of the challenges faced, as follows: "We have particular skill gaps in basic skills for employability, including literacy, numeracy and use of IT; intermediate skills at apprenticeship, technician, higher craft and associate professional level; mathematics; and management and leadership" (p. 12). In the '14-19 Education and Skills White Paper' (Secretary of State for Education and Skills, 2005) again there is no definition, and although 'science' is mentioned numerous times, there is no indication which skills the teaching of science might provide or enhance. The Third Report of the House of Commons Science and Technology Committee (2002) proposed that a "new National Curriculum should require all students to be taught the skills of scientific literacy" and did contain a definition of investigative skills (see Figure 4.5) in relation to KS4 science, taken from the QCA criteria for GCSE at the time, as well as the provision of development of technical skills through the GCSE Applied Science.

Figure 3: Investigative skills: extract from QCA's specification for GCSE science

Candidates must be able to:
- (a) Devise and plan investigations, drawing on scientific knowledge and understanding in selecting appropriate strategies;
- (b) Demonstrate appropriate investigative methods, including safe and skilful practical techniques, obtaining data which are sufficient and of appropriate precision, recording these methodically;
- (c) Interpret data to draw conclusions which are consistent with the evidence, using scientific knowledge and understanding, whenever possible, in explaining their findings;
- (d) Evaluate data and methods.[17]

Figure 4.5. Definition of investigative skills according to the Qualifications and Curriculum Authority (QCA), taken from the House of Commons Science and Technology Committee Report (2002, p. 12).

Teachers may have been exposed to rhetoric and documentation related to the Skills Strategy, but this does not comfortably explain the ease with which they seem to use the concept of a 'skill' without a clear definition. This was briefly but explicitly explored with a subset of the teachers as it seemed appropriate in our interviews. Teacher A1 for instance, when asked what 'skills in science' are, listed: "collecting data, planning an investigation, looking at your variables, collecting data, analysing data, evaluating, being safe, repeating, accuracy, reliability" (33-34).

This matches the definition in the House of Commons report quite well (see Figure 4.5), and may be a reflection of Teacher A1's initial teacher training as this occurred around the time of the report (2002). It does not, however, include the socio-scientific aspect of "appreciating the impact of science on society" and the more general emphasis on 'the skills of scientific literacy' as intended by the new GCSE courses which were proposed to be piloted by the report (House of Commons Science and Technology Committee, 2002, p. 12). Teacher F1 came much closer to this when he explained:

> "Well *we* refer to [HSW] as scientific skills. A large part of it is planning, hypothesising, doing, analysing and evaluating experiments but also the area I am very keen on is what actually science is. The kids think everything in science is a fact and it's trying to get over to them that actually everything is theories, models, that whole idea that if somebody comes up with a better idea that better fits the evidence, or someone discovers some new evidence then the models and theories will change, and it's trying to get that through to the kids really. There are a whole load of things that go with that but that to me is as big a focus as the actual experimental skills." (F1, 23-29)

Although F1 started with the bold statement that in his department HSW is referred to as 'scientific skills', which would be worrying for the reason Hunt (2011) advanced so eloquently, he did not *identify* HSW with 'scientific skills' in his own thinking. He made a distinction between experimental skills such as planning, hypothesising etc. on the one hand, and all the other aspects of HSW he sees as important on the other, e.g. an appreciation of evidence and the role of models and theories in science. Neither from the quote here nor from anything else in our interview can the conclusion be drawn that teacher F1 views skills as anything other than an ability which can be practised to be improved. Teacher F1 seemed to make a philosophical distinction between *how science works* and *what science is*.

With respect to 'the skills of scientific literacy' it is noteworthy that two teachers, C1 and C2, referred to 'scientific literacy' when what they actually meant was simply 'literacy', the ability to write using the correct language and language structure, applied to science lessons and assessment. Although literacy skills are part of science teaching and need concerted effort in the light of HSW and the new long-answer exam questions (see section 4.3.7), C1 and C2's confusion does not cause concern in the context of 'skills'. They are both prolific users of the words 'skill(s)' but almost always in the context of 'doing', 'building' and 'repeating', and firmly *next to* 'knowledge' and 'understanding' rather than in any way overarching it, although Teacher C2 made one slip when she said her pupils "should really just know the skills by the time they get to KS5" (169-171).

Teacher D1 was vocal about the skills required for one of the pieces of controlled assessment which was part of the OCR Gateway GCSE they were running: "the intentions behind it are great but the skills that it assesses are difficult for even the brightest pupils to understand [sic], never mind actually do" (134-135). She expanded that this concerned the type of documentary research the pupils were required to do, and the skills needed to evaluate the sources that could be found. Despite the nice example of convoluted language used by people regarding 'skills', this displayed a level of understanding of the requirements that is not found in all teachers, concerning the delicate balance between the knowledge of and ability to do something. There are other examples of variations in this understanding, or at the very least variations in the way this understanding is expressed and the word 'skill' is used, such as: "that is something if they ever are going to go to university to write papers it's a skill that they need to know" (G2, 469-470), when discussing the requirement for A-level students to appreciate that "the findings of scientists are subject to peer review before being accepted for publication in a reputable scientific journal" (2007, p. 39).

On the other hand, there are examples of clear use of 'skills' referring to abilities which can and have to be practised, even with A-level pupils, such as: "I have banged on about practical skills so things like standard format, when you put a table if there is a percentage you put that at the top of the column, units, writing with a pencil" (J1, 317-319).

In this section some of the issues around the sometimes cavalier use of the word 'skill(s)' were explored. As the NC does not consistently treat 'skills', 'knowledge' and 'understanding' in their appropriate conceptual context, it is important to gauge whether practitioners have a suitable understanding of the correct use of each of the terms.

4.3.7 Emphasis on assessment and examinations

4.3.7.1 Motivation to be influenced by summative assessment

Although all the teachers in this study were generally positive about the emphasis on HSW in the NC for science, and some teachers got very enthusiastic about the teaching of specific aspects of it which leads to the conclusion that at least some of them have *intrinsic* motivation to teach HSW, summative assessment may also provide *extrinsic* motivation to include certain elements of HSW in a certain way in teaching. An example of this was presented in section 4.2.1: Teacher J1 talked about having a "vested interested" in HSW because of his awareness of HSW being "part and parcel of the exam" that he "want[ed] [his] kids to pass" (251-252). This sounded like he needed a bit of extrinsic motivation to be convinced of some of the benefits of including certain aspects of HSW in his teaching.

4.3.7.2 GCSE assessment at Key Stage 4

Even with a National Curriculum, the Awarding Bodies for GCSE developed different modes of assessment, especially for the 'coursework' as it was until 2011. This has become the 'Controlled Assessment' from 2011 and the variations are much more limited. The teachers in this study worked with three different GCSE specifications between them: AQA (the majority), OCR Gateway (two schools, of which one changed to AQA between the first and last teacher interviewed) and OCR Twenty-First Century Science (TFCS, one school). The assessments connected with these three specifications will be presented briefly.

AQA (2012a)

AQA provides a number of routes through GCSE, resulting in one, two or three GCSE qualifications. For all routes (apart from the Additional Applied Science option which none of the schools in the sample offered), 25% of the marks are from the Controlled Assessment, the rest from written exams. The AQA Controlled Assessment is an Investigative Skills Assignment (ISA). Until 2011 the experimental work to be performed was fairly rigidly prescribed by AQA, and the main assessment materials started from the assumption that all pupils had already managed to collect some data. The questions in the assessment materials were highly structured on the whole, and section 2 was devoted to the analysis of secondary data. From 2011 the assessment starts from a specific hypothesis, which is either provided by AQA or devised by the pupil depending on their level, after which the pupil researches the literature to find out how the hypothesis might be tested. The pupil then plans the investigative work on paper, under exam conditions, working from an almost unstructured format (see Figure 4.6).

In this question you will be assessed on using good English, organising information clearly and using specialist terms where appropriate.

Describe how you plan to do your investigation to test the hypothesis given.

You should include:

- the equipment that you plan to use
- how you will use the equipment
- the measurements that you are going to make
- how you will make it a fair test.
- a risk assessment

Figure 4.6. AQA Controlled Assessment relating to 'planning'. This question, taken from the 2011 specimen paper for Concrete (AQA, 2012b, p. 3), is very similar in all papers.

Only then would the pupil perform any experimental work, from an approved plan (either their own or provided by AQA). The first part of section 2 of the assessment is related to this experiment, with only the last part devoted to secondary data.

Teacher I1 was the most extensively vocal about the different parts of the assessment for AQA GCSE. He felt the exam questions in the ISAs gave his pupils the opportunity to display their understanding of their own investigations as well as those from a different context so that they could apply acquired skills, and that the brighter students achieve better results because they "can apply their knowledge more effectively" (427). He was enthusiastic about the written papers, too: "I think the AQA B1, C1 and P1 papers are some of the best at assessing and challenging students, and testing their understanding of HSW" (460-461), referring especially to data handling questions. His colleague Teacher I2 was not so positive about ISAs, especially the repetitive nature of the practical aspects.

Teachers have sometimes let their pupils try as many ISAs as they could to get the best possible marks, resulting in what Teacher H1 called "going through ISA season of doing hundreds of ISAs" (239-240). The new Controlled Assessment, however, will not allow that level of re-sitting. It also takes just that little bit longer, and requires some extra organisation on the part of the teacher as well as the pupils, which especially Teacher E1 flagged up:

> "We're not very happy about it, the new AQA coursework. It's... just the kids seem to find it way too difficult. It's way too extended. It takes about five or six lessons to do it. To have a full class for five to six lessons in a row is probably unheard of." (E1, 42-45)

He talked about pupils losing research material taken for homework, and weaker pupils simply not being able to sustain the momentum for long enough. There are ways and means to get round every problem, and a creative solution to the time issue will be discussed further in section 8.4.2.

OCR Gateway (2012a)

OCR Gateway, similarly to AQA and the others, provide a variety of routes through the specification and assessment. In the version valid until 2011, the 'coursework' consisted of either a unit of 'Can-Do' tasks and report on 'Science in the News', or a unit of Research Study, Data Task and Practical Skills. This provided one-third of the total GCSE marks. The new version Controlled Assessment, from 2011, has a weighting of 25% and consists of three parts: 'Research and collecting secondary data', 'Planning and collecting primary data', and 'Analysis and evaluation'. Exam conditions are applied for part 3, a written paper, which has some unstructured questions in which the quality of written English is assessed alongside the science.

Although not all teachers were equally enthusiastic about the coursework itself, they did acknowledge that the way it is assessed influenced their teaching. When asked directly about assessment practices, Teacher D1 said "the other one is this awful Science in the News thing that they have to do but I do all the things [practising skills related to the assessment, such as researching] on that" (421-422). She claimed that the requirements of finding good quality evidence sometimes simply could not be fulfilled, so that the pupils all ended up with exactly the same sources, and they found the task difficult.

Teacher E1 encountered similar problems with the research aspect of the AQA ISA, to the point that he asked AQA: "Can they do research on general HSW skills, can they research what it means to have a control variable, have an independent variable, have a dependent variable? To make it a bit more generalised?" (69-71) but was told the pupils have "got to have research that dictates, or provides, information for their actual method" (72-73).

Teacher C1 was more positive about the coursework itself, but did pose a rhetorical question about practising for examination: "Maybe the problem just lies with measuring because, let's face it, as soon as you have had Science in the News in place for four or five years everybody is bloody good at delivering it, aren't they?" (809-810).

That last point brings it round to teaching to the test and rote learning, which will be discussed further in section 4.3.7.4.

OCR TFCS (2012b)

In OCR TFCS from 2011 the Controlled Assessment unit consists of a Case Study and Practical Data Analysis (in the Core and the Additional Science GCSEs) or a Practical Investigation (in the Biology, Chemistry and Physics GCSEs). Exam conditions are applied to the final stage of the 'Practical' tasks, when the pupil writes a report of the practical work undertaken.

Teacher B1 is the only one with first-hand experience of TFCS. He did not mention anything about coursework or the imminent change to Controlled Assessment. He did, however, refer to a legacy mode of assessment: "to be fair, OCR have had the 'Ideas in Context' exam, in which [pupils] get given some information to read and then the kids have to answer some questions on that [...]; that's an interesting way of doing that" (751-757). This was in reference to the current lack of successful and interesting exam questions on HPS and socio-scientific aspects of HSW. Teacher B1 was much more positive about the exam questions on data handling, which were also mentioned by a variety of other teachers as more successful than any other type of HSW-related exam question.

4.3.7.3 Assessment of HSW at A-level

Some of the teachers were adamant that they perfused most of their lessons with HSW, at A-level like at KS3 and KS4. Teacher C1, for example, found that the OCR Physics B (Advancing Physics) course is "completely themed in the real world setting" (400-401), which to him meant that the emphasis was firmly on HSW rather than scientific content knowledge. This would not have been because of the assessment load. A-level assessment contains very little HSW, according to many, apart from the aspect of practical and investigative skills. Teacher F1 was very clear about his position on this:

> "If you look at the A-level papers, they claim there is HSW in them but I will be damned if I can find it! So sometimes they will claim 'well that question is HSW' but you think 'that is so tenuous it's unbelievable!' It's not really there at A-level. (F1, 276-279)

Teacher D1 would agree "obviously you do experiments, you do practicals, so that is part of it, but there is not really the same emphasis on communication and on history and on looking at evidence, that's not really there in the same way" (193-195). She added that "while [exam questions] are sometimes phrased in terms of 'what are the benefits, what are the advantages', they are not talking about wider issues, [...] and the mark scheme is really clear on what it wants" (229-231).

Occasionally mark schemes can be too 'clear', as Teacher C1 asserted that he had seen A-level Biology exams "where if [pupils] wrote 'diffusion through a semi-permeable membrane' then they don't get the mark because they have to write 'osmosis' – it's wrong isn't it?" (272-273). No matter how good a teacher you are, there is a limit to what can be taught and remembered, and C1 pointed out that "that element of this pointless remembering is the lowest cognitive challenge" (268-269). Although this example represents scientific content and is thus quite far removed from HSW itself, it is not in the spirit of HSW.

One of the recent changes of A-level exams is the inclusion of 'Suggest' questions, which for Teacher K1 has meant teaching a new exam technique (see section 4.2.2).

When thinking about the emphasis on HSW and its assessment at A-level, Teacher E2 pondered: "I query its usefulness at A-level" (710). She felt that the exams, certainly in chemistry, contained a lot of closed questions, resulting in "regurgitating of acquired knowledge, rather than any useful debate or analysis" (713-714). She exclaimed: "If you want them to memorise facts, just call it content, don't bother calling it HSW, please!" (714-715). This needs further consideration in section 8.3.

4.3.7.4 Teaching to the test, and rote learning

With practice, both teaching and learning can improve (see also Teacher C1's assertion in section 4.3.7.2). It is no surprise that teachers see opportunity and reason to use the summative assessment as an influence on their teaching. Teacher F1 went as far as to say:

> "If they change the assessment it does usually drive changes in the teaching. It shouldn't be that way around but the reality is that it is. It often is the only way to get people to change what they are doing is to assess it. It is sad and it is not the way I think education should work at all, but the reality is that is often what happens" (F1, 258-265)

Teacher E2 would agree there is a disagreement between what would be part of a good education and how assessment influences what actually happens in lessons:

> "I think ideally HSW should be about getting kids interested about discussing topical issues in science and getting them interested and engaged in that. [...] The problem with that kind of thing is: it's very hard to assess in an exam because any relevant science and any controversial science is not going to be very assessable in the fairly formulaic way that the exam questions are designed." (E2, 51-55)

Ideals aside, Teacher E3 felt that she would be doing her pupils (and her school) a disservice if she ignored assessment in her teaching. When asked whether her teaching is influenced by it, she answered: "Has to be! Doesn't it? Because at the end of the day we are judged on that kind of thing, and the school itself is judged on that kind of thing" (383-384). She concentrated considerable effort, including out-of-lesson time, on exam technique, "because it makes two, three grades difference" (388-389).

Although the assessment of HSW is meant to be around 25% of the total assessment (there is some variety at the different key stages), there was considerable variety in the amount of time teachers estimated they spend on HSW in lessons. Teacher G1, for example, thought it takes him no more than 10% of teaching time, regardless of the level. When asked how that works for the rest of the HSW marks, he replied:

> "Well, because it doesn't take so long to cover what's needed, in order to get them to pass the exams. And the fact is, if we spent 25% of our time on HSW, at GCSE, we wouldn't get through the course! [And at A-level] perhaps even more so" (G1, 170-176)

While Teacher G1 did not use the words 'rote learning' per se, other teachers were not shy. Teacher H1, for example, was very explicit when she explained why she had issues with the GCSE ISAs and HSW:

> "The questions that they are asking is parrot fashion learning and the questions are too complex sometimes for the answers, the answers that they want aren't what the pupils give, and the pupils might give a perfectly good answer but it's not what they want and it hasn't worked!" (H1, 431-434)

She felt that certain aspects of HSW, especially debates, "[turn pupils] off; they see it as silly fluffy stuff when you want them to debate and you have to write an exam answer on some 'fluffy stuff' as they call it" (438-440). She added: "You don't need to be examined on it!" (444). Teacher H1's outburst was not simply a statement about the possibility of success in GCSE ISAs through rote learning; it touched on deeper issues of the possible failure of HSW to engage pupils with science, through a lack of successful and appropriate assessment. Despite this show of negativity, Teacher H1 was convinced that rote learning could not be successful for her A-level pupils, as she claimed that A-level exams require more understanding and an "ability to interpret that onto a different situation", and that pupils "wouldn't have been able to answer the questions in the exam paper if all they did was learn it parrot fashion; they wouldn't be able to interpret the questions if they didn't actually understand it" (388-398).

The lack of successful and appropriate assessment was also a reason for frustration for Teacher D1, who felt her pupils "are missing out there because if [she is] teaching them a skill the point is that they can then apply that skill to an unfamiliar situation and [she doesn't] see a lot of unfamiliar situations anywhere at all" (496-498). She therefore thought "it more points the way to how they want [teachers] to teach it [...] because ultimately it feels at GCSE like if [pupils] rote learn then they will be fine" (494-495).

There is a certain amount of disagreement among the teachers about whether all aspects of HSW might be rote learnt. Teacher F1, who was so pragmatic about assessment being a driver for change in teachers' practice, argued there were certain aspects of

HSW, and he was specifically referring to 'skills', that could not be rote learnt. It is possible that Teacher D1 saw the rote learning of skills as a process of practice until robotic reproduction was feasible which, if pupils are not presented with surprising or unfamiliar situations in their exam situation, might well be successful.

As teachers are looking to assessment materials to guide them in their teaching and to prepare their pupils for exams, there is opportunity to make more of that link between exam questions and teaching, and perhaps turn the process on its head. That was part of the project led by Hunt in which one of the aims, among others, was "to create a bank of test items [to assess HSW] from external, written examinations that provides examples which help teachers understand the expectations implied by statements in specifications" (Hunt, 2011, p. 1).

In summary, teachers are heavily influenced by assessment. With regard to HSW, this meant a certain amount of teaching time was dedicated to exam practice and exam technique, whereas aspects of HSW which do not seem to be overtly assessed, or aspects for which exam answers can be rote learnt, tended to be played down in teaching.

4.3.8 Emphasis on textbooks

Although only around a quarter of the teachers acknowledged any kind of reliance on textbooks early on in our interviews, others referred to them later on, sometimes pulling them out of cupboards to look up something specifically or show the way HSW is incorporated in them. One teacher had her trusted A-level course syllabuses on her knees all the way through our interview.

Teacher B1, for example, acknowledged that he might not have known about HSW if it was not for AQA, who "used to make a big deal out of it, so in the textbook you have a section that says 'HSW' on the right-hand-side" (12-14). Immediately following, when asked what to him the main elements of HSW are, he replied:

> "I think it's about understanding the links. So you get the students to do a practical, [...] and then you have to say 'right, I have to do something with this [sic] data', so you've got to turn it into a graph or something so you can see it and understand how the data is working. I think that is, kind of, the

> aspect of HSW and then you have to bring that back round into the issues which is what the content of the GCSE is looking at, so the HSW is the actual science bit, if you like, it's the 'looking-for-the-links'" (B1, 18-25)

He thus displayed a fairly complete philosophy of science which was not dominated by the terminology so regularly used by AQA teachers. Teacher B1 has since changed schools and started teaching TFCS of which he said: "the way it is with Twenty-First Century Science is it's built in so you don't actually see it when you're doing it, if you know what I mean; so you don't particularly know that you're doing it" (7-8). That built-in quality was also appreciated by Teacher I2 regarding SNAB (see section 4.2.3). Teacher G2 was happy to take guidance from the syllabus, as she trusted that "this is obviously tried and tested, that some of [the suggested activities] are good ways to get the information across, or the idea across or the skill across" (445-447).

Similarly to Teacher K1's assertion that there have been other initiatives, Assessment for Learning (AfL) in his case, which have influenced teaching practice regarding HSW, there were other teachers who brought intervention projects to the fore such as the Teacher Effectiveness Enhancement Programme (TEEP, 2012) and Cognitive Acceleration through Science Education (CASE) (King's College, 2012). These were designed and implemented before HSW was emphasised in the NC. Some teachers have found the resources helpful for the teaching of certain aspects of HSW, although at least one of them acknowledged that that was not what they were designed for.

While the reliance on commercial and other materials was variable, many teachers acknowledged that they had been influenced to some extent. It was especially noticeable in some of the teachers who taught AQA GCSE, where the use of specific terminology relating to investigation is so obvious.

4.3.9 Ignoring one or other aspect of HSW

Some teachers acknowledged that they played down certain aspects of HSW, notably communication and applications/implications, because of the absence of challenging questions in the assessments (see sections 4.2.2 and 4.3.4). They felt that, where they *are* assessed, common sense is sometimes enough to score the marks, as Teacher J2 noted:

> "Some of it... it tends to be fairly common sense; there will be a question and it will say 'why is it important to test theories by experiment?' which really... it's only the very weaker students who would have no idea of how to answer that and the brighter ones would have a very good idea, they would feel like it is common sense. I suppose you hope that you will have covered those ideas and talked it through with people and so on." (J2, 167-172)

Teacher J2 seemed to imply that explicit teaching is not always necessary, because those ideas will bubble up by other means and in other contexts. Sometimes, however, some teachers claimed, the answers to such questions can be rote learnt (e.g. the advantages and disadvantages of certain technologies, where the marks for economical and environmental points are rather obvious). Teacher E2 was even blunter in her assertion that, especially with triple science groups:

> "if you're trying to get through it quickly, that is exactly what you have to do, is: 'Right, here are three pros, here are three cons, learn them please, folks! Regurgitate! And... let's move on!'" (E2, 681-683)

Newly qualified Teacher G3 was more idealistic about her pupils learning something longer-lasting about (dis)advantages, but also realistic about the potential for rote learning, as she said:

> "I normally get them to write a couple of pros and a couple of cons. [...] They just have to be able to list two, so that I suppose the students who don't get the discussion [held in one of the lessons], will just learn off by heart, two advantages and disadvantages, but I'm hoping they'll be able to reason them, and explain them a bit more even though in their exam they might only have to say a sentence." (G3, 297-305)

Sometimes the overlooking of one or other aspect of HSW is not so much an act of neglect as just that: overlooking. For example Teacher J2, who concentrated on HPS and socio-scientific aspects initially, mentioned investigations almost as an afterthought: "What maybe I haven't noticed was that it says 'carry out experimental activities'; again that seems to be pretty clear" (40-41). This is more a matter of not having memorised the statements of HSW in the NCASC, rather than ignoring investigations in his teaching. Teacher I2 mentioned similar problems, thinking he knows what is in the curriculum documents, and following examiners' suggestions of reading up on the Assessment Objectives in the specification documents, but then promptly forgetting them again.

Teacher B1 also discovered a 'new' part of the HSW curriculum as our interview developed: "Well, yeah... I deliver [history of how a theory develops]. I'll be honest, I wasn't aware that was in the HSW section; I sort of took that as being read" (64-65). Teacher D3 similarly had not really been aware of the requirements of the HPS part of HSW, did not feel confident to talk about it at all, and said she was "going to have to look at that [her]self, in [her] own time" (599). Such lacunae in teachers' own development are discussed further in section 7.4.6.

Ignoring or playing down an aspect of HSW could easily be construed as reluctance or even subversion in the face of the curriculum development, but some would argue that it comes down to pragmatism. As Teacher G1 noted:

> "I tend to be a little bit cynical, really. I think you'll find that, amongst anyone who's been doing a job for a long while, the pragmatism is... at KS3, suppose they want me to do something, and I don't quite do that, how will they know? How will it be known? My main concern is the children, and that what I do should educate them towards that what they will need to do next, so for example at KS4, or at A-level." (G1, 11-15)

Also, the overall tendency is that even the most cynical of the teachers considered HSW to be valid as a whole, and they would not want to leave any of it out completely (see section 7.2).

4.4 Summary

In section 4.2 two frameworks were introduced.

The first represents the way teachers were divided on the question of whether they have changed their practice at all as a direct result of the appearance of HSW in the curriculum. They fall into three groups:

- The "changes-certainly" group who immediately acknowledged that HSW had brought certain changes to their practice;
- The "doing-already" group who were confident that they were doing it all before and did not waver from that position;
- The "doing-some-already-but" group who claimed they were doing some or all of it before, but who started to qualify that position at once.

The second framework is 'the spectrum of readiness to change', which represents how teachers responded to the change under study. Some teachers should be considered 'pioneers', as they had already started changing before the curriculum required them to do so. Others are 'embracers', who recognised the change as something they wanted to partake in immediately. A third category is formed by the 'followers', who slowly introduced changes as they started to recognise the potential benefits or the requirements of them to do so.

In section 4.3 teachers' emphasis on the three main strands of HSW in the National Curriculum has been discussed, namely

- Practical work and investigation, where the freedom to have lesson objectives about skills and processes (rather than just scientific content knowledge) and the link to Sc1 came to the fore;
- History and philosophy of science (HPS), which had been referred to as Sc0, and where the debate about the need for explicit teaching of HSW started;
- Socio-scientific aspects, with an emphasis on the human nature of science, and more about explicit teaching.

In addition issues have been raised regarding teachers' current practice with respect to

- 'Skills', a term which is used lightly, not just by teachers, but where the definition of 'ability which can be practised' shines through;
- Assessment and examinations, of different modes and levels, with reference to teaching-to-the-test and rote learning;
- Textbooks, which are relied on to varying degrees by many teachers, also for their own development.

As well as presenting teachers' current practice, the section examined some teachers' tendency to play down certain aspects of HSW in their teaching, and their reasons for doing so. The reasons can be grouped under one heading: 'pragmatism'. If the pupils are likely to need something in their exams or in the next stage of their education, the teacher will do their utmost to include it in their teaching in an appropriate fashion.

5 Teachers' reflections on science and science teaching

5.1 Introduction

In addition to giving an insight into teachers' current practice as presented in chapter 4, teachers were asked about their current thinking of what science is, and also to reflect on the teaching of secondary school science in general, with an emphasis on *How Science Works* (HSW) (research question 2). The influences on teaching and thinking as teachers advanced them form such a self-contained section that they are presented separately in chapter 6. It is not always easy to distinguish between teachers' descriptions of their thinking and reflections on their practice, and some comments refer to both.

Asking teachers what science means to them, and how they think science works, does not do justice to the vast literature about teachers' views of the Nature of Science as discussed in Chapter 2. It does, however, go some way in the context of this study to understanding the teachers' thinking about the content of the curriculum as they are required to teach it. This is investigated in section 5.2. Many teachers are aware how HSW developed from earlier sections of the National Curriculum (NC) (section 5.2.1). Participant teachers' views of each of the three main subsections of HSW are presented in sections 5.2.2-5.2.4.

When considering teachers' reflections on teaching science, there are a number of factors which are so prominent that they deserve a separate section. *Skills* have already been discussed in the context of teachers' classroom practice (see section 4.3.6), but they require being revisited here in section 5.3.1. Other factors, such as the role of science in education, the use of learning objectives as a starting point for planning, considerations of progression, and whether HSW should be integrated into lessons or not, are presented in sections 5.3.2-5.3.5.

5.2 A brief discussion of what teachers think science is

5.2.1 The HSW pedigree

As already became clear in chapter 4, some of the teachers in this study were aware of and comfortable with the curriculum developments leading to HSW. Teacher F1 was confident that he recognised Sc1 and even AT1 in the investigative aspects of HSW, and History and Philosophy of Science (HPS) reminded him of what has been colloquially known as Sc0 (see section 4.2.1). HSW did not develop in a vacuum, and teachers recognised that science is not complete without HSW, in whichever guise.

5.2.2 History and philosophy of science

Some teachers' philosophy of science is more mature, others' more naive. Teacher A2 talked about "prove" and "true" although he also said, about the Big Bang:

> "I have trouble getting my head round some of that, so I tell them 'Look, the currently accepted theory is this one. It might not be the be-all-and-end-all, but it's the best guess we have at this minute, and you have to take it as fact at this moment in time. But it might change.'" (A2, 635-640)

So he does appreciate that science is not simply a body of facts. Teacher F1 is rather mature in his philosophy regarding facts, as presented in sections 4.3.4 and 4.3.6. Teacher D2 formulated his thinking about science, and the role of facts, evidence, enquiry, proof and doubt, as follows:

> "And before you can actually have anything as theory you need some evidence to back it up from its initial idea and fact, whether that word truly exists in terms of that I don't know, but the only way to have fact is if you have enough evidence to prove beyond doubt – and never mind that what do they use in law, beyond reasonable doubt – I think just beyond doubt, which I think is quite difficult." (D2, 105-108)

Teacher D2 seemed to be struggling with a Popperian view of science relating to conjecture and refutation, but, again, would not present science as a body of facts. This is something that Teacher I1 was also very concerned with, because he "think[s] there's a real danger that we, as teachers, present science as a set of facts" (527-528). He saw it as his task to help his pupils to "make the link that these had all been found by experimental approaches" (533-534).

None of the teachers had a truly modern appreciation of the philosophy of science, and only one, namely Teacher J2, displayed any more formal knowledge of it (see section 4.3), as he said:

> "I kind of pretty much teach the way I believe it to be. So I do correct people if they are talking about theories being proved because I am of the opinion that you cannot prove a scientific theory – there is no such thing as a proof of it, I don't know whether that is Karl Popper or whatever – and I will just say 'you can have evidence for a theory, or you can disprove' and so I think really there we have discussion about this and I try to get them towards the idea of a theory being the best possible model that we have at this time." (J2, 69-74)

When presented with the question about what science is to them, and how, in their view, science really works, three teachers instinctively said something along the lines of 'science is everywhere and everything'. Although this is not very helpful as a philosophy of science, it gave an indication of the sense of wonder that presumably brings a great many people to science and science teaching.

Some teachers acknowledged that although they must have had some understanding of the requirements of science teaching beyond scientific content knowledge before 2006, their understanding of HSW developed with teaching it. Teacher I2 developed alongside SNAB (see section 4.2.3). Teacher A1 acknowledged that it took time: "I don't think I really understood it as such at Key Stage 4; I think it was more when Key Stage 3 was brought in that I understood what it was" (7-8). She went on courses where she was introduced to "the new Standards site stuff [(DCSF, 2010a)]… and that seemed to make more sense to me" (21). Then, even more recently, "the APP's brought it in a lot more" (49). APP is 'Assessing Pupils' Progress'.

The responses to the deceptively simple question of what science means to them have highlighted the need for more teacher development, which will be discussed further in section 7.4.6.

5.2.3 Investigation and enquiry – doing science as a scientist

Teacher G1, the longest-serving in the sample, explained what science is to him, with respect to investigation and enquiry. He included links to historical developments in science teaching in England, related to pedagogy and philosophy, where he acknowledged that "it's not quite the sort of Nuffield idea of 'here's some equipment, go and find out for yourself'" (30-31), but he felt it important for pupils to become confident to not "take a teacher's word for it" (33). He added:

> "I think that is *the* most important thing. The second thing is having suitable vocabulary to communicate with other people what you found, and perhaps those are *the* most important things. [...] That's the whole process, to my mind" (G1, 34-40)

He brought in links to socio-scientific aspects, of using other people's ideas and working together, learning from others, of doing science as a scientist within the boundaries of secondary school science. He appreciated that pupils cannot discover new science, but he seemed to have found a way to make it new and challenging to pupils.

The whole process of doing science as a scientist and finding out how the world works by experimentation was also highlighted by other teachers. Teacher I3, for example, said:

> "HSW to me at a basic level is the process that scientists take in order to get to the final product, so there's [literature] research, then there's obtaining results, there's analysing results, there's evaluating results before you go and publish it." (I3, 7-9)

Another example was Teacher F3 who said "it's really about understanding the process of scientific investigation, and how scientific theories are developed, come about, are proposed, are tested, peer-reviewed" (12-13). Teacher F2 hastened to add that in an investigation it is about asking and answering questions, not just simply reporting what you see.

From the interviews came a sense that there is more to scientific investigation in secondary school science than following a recipe and going through the steps of some kind of method. 'The process' is more varied. Pupils are allowed to question the teacher's autonomy, and are actively encouraged to ask 'why?' and to search the literature for ways to answer questions. The thinking behind the teaching of some of the skills involved is discussed further in section 5.3.1.

5.2.4 Socio-scientific aspects

One of the aspects teachers picked up on, regarding HSW, is the duty science has to society, and a teacher's own role in helping to uphold science's carefully built reputation, "won on the back of learned people doing educated research, analysing what they've got [...] before they advance it onto the world" (I3, 526-527). Teacher I3 explained: "HSW has always existed, and it is just about doing things properly, [...] teaching good habits, [...] preserving the good reputation of science as being a good discipline" (520-534).

One of the newly qualified teachers in the sample, Teacher F2, acquired first-hand experience of problems regarding the reputation of science, and her belief and philosophy were tested. In one of her teacher training placement schools she disagreed with another teacher on the principle of whether a graph which is "supposed to be a straight line" (73) can be forced to be a straight line with data from an Investigative Skills Assignment (ISA) experiment. She tried to stand her ground:

> "I suppose it was just trying to explain [...] that if scientists had been doing that from the beginning, trying to force their graphs to do things which they are not actually doing then where would that leave us with our scientific theories?" (F2, 85-88)

It is that aspect of science which teachers try to instil in their pupils: how to judge evidence on its merit. As Teacher B1 considered: "Well, I think what we're trying to teach them is the skills, isn't it, to identify when their data is reasonable data" (584-585). He added:

> "That's something else you have to get across, isn't it, that scientists don't always... they present what they see; 'say what you see', that's what science is, and sometimes [scientists] will see different things. And it's important [pupils] know so they can make a decision about which one's the more useful" (B1, 587-590).

Teacher D1 put this role of the science teacher into context, when she said: "I suppose as a scientist… teachers are often a little bit uncertain on whether to call ourselves scientists; we work in the science industry in the sense of 'that is what we work with everyday'" (511-513). She then related that to the roles of all the other humans in science, when she added that

> "anything that is developed scientifically sits in a context of 'well this is how it was discovered and these are the ideas behind it and this was the evidence put forward, this was the controversy at the time, these are the people that fought over it, this is the idea we have now, and this is how it can be applied.'" (D1, 517-520)

Despite, or perhaps due to, the difficulties in understanding the interplay between science and society, teachers seemed to keenly feel their responsibility of instilling an appropriate sense of trust in science in the next generation of citizens and scientists.

5.3 Teachers' reflections on teaching science

5.3.1 Skills

As Teacher F1 said: "Well *we* refer to [HSW] as scientific skills" (23). He displayed a rather complete understanding of the skills and other requirements of HSW (see section 4.3.6). Teacher A1 was another who started with a general remark that she felt that "the skills of science rather than the content of science, is How Science Works" (25). She reeled off a list of what she saw as skills (see section 4.3.6), such as planning, collecting and analysing data, evaluating etc. – all related to practical and investigative science – before she claimed that "if you didn't have your HSW, then the subject content wouldn't make any sense anyway; I don't think you'd be able to access the content if you couldn't do these skills" (500-502). The practical skills have been discussed in section 4.3.6, but teachers also talked about more general thinking and learning-related skills, which will be discussed here.

Communication skills

'Communication skills' form a separate section of HSW in the key stage 4 (KS4) NC (see appendix A). Although some of the 'skills' listed, such as 'interpret', can be problematic if 'knowledge and understanding' are included (as discussed before in section 4.3.6), few teachers would maintain that communication skills are not an inherent part of science teaching.

The terms 'debate' and 'discussion' were sometimes used interchangeably, although some teachers made a clear distinction between the two and would use the term 'debate' only for a discussion where there are two camps who try and convince each other of the merits of their position. Some teachers acknowledged that it is difficult to run a successful debate and/or discussion. They put forward a variety of reasons:

- "Discussions, I find them hard to manage in a class" (D2, 247);
- It is important to consider the learning objectives, and debates/discussions do not necessarily fulfil what they set out to. For example Teacher I1 had come across a suggestion that they might provide pupils with an understanding that there can be differences of opinion within the scientific community, which may influence citizens' decision-making. He said: "I'm not sure that having a debate or a discussion always leads them to gain that understanding; I think the discussion or the debate helps them formulate their ideas about the science" (359-361);
- Debates/discussions are not appropriate if pupils are not ready: "It's either that they haven't got the scientific background or that they haven't got the more social awareness that they would need to be able to have a reasoned ethical debate, which is another key issue" (F3, 91-93).

Teacher I2 was also aware that especially debates about ethics may require pupils to have a maturity which may need to be guided by an awareness of formal ethics frameworks and standpoints, which SNAB provides in the course materials. He might, he said, "not use the word utilitarianism but [he]'d talk about that and [he]'d talk about all the different ethical viewpoints and then allow them to pin their views on that" (358-360).

Despite potential difficulties, teachers saw enough reasons to persevere with using discussions or debates in their teaching. Teacher B1, for example, claimed it goes well with the style of 'The lazy teacher's handbook' (Smith, 2010), while he hastened to add: "It's called 'the lazy teacher', but it's not!" (275). The reason it fits so well, Teacher B1 argued, is:

> "That way you've got them in small groups, so you can actually go round between the groups, and discuss what they're doing and make sure they're in the right idea, and I think that prepares them better for the future, for when they're out in the wide world working, and I think it's generally a more engaging way to work." (B1, 275-278)

Teacher I3 argued that discussions are simply part of the rich tapestry of science teaching, because, he said, "if you have a debate, if you have some sort of a performance, you're just adapting something to suit a specific learning need; I would do it for that reason, rather than do it because HSW told me" (427-428). If it fits with the learning objectives, it is the right way to teach.

Teacher I2 was not the only one who claimed to use opposing viewpoints in debates (see section 4.3.5). Teacher E3 claimed it can be a very successful way of getting pupils to think for themselves, as she said:

> "that helps because just spouting what *you* think, or what your dad's told you you should think, you don't actually particularly think around it, but if you get one that's in opposition, you have to be more inventive about it, and actually think about the possibilities." (E3, 356-358)

Teacher H1 reiterated that debates may be very worthwhile, and would certainly be on her list of classroom activities, but she had serious issues with a direct link with assessment, as she said: "I forward articles that might be quite interesting and look at an article and ask 'what is your opinions on it etc.'; it is good to get them debating but I don't think they should be examined on it" (85-87).

One other aspect of communication skills was very noticeable in the interviews: scientific terminology, especially related to Assessment and Qualifications Alliance (AQA) requirements. According to Teacher I3, for example, "'precise' and 'accurate', that took a lot of getting used to, what was exactly what; 'sensitivity' then, 'sensitivity' and 'resolution', that's another grey area" (646-648). Teacher F1 and his department have also struggled with some of this terminology (see section 4.3.3). While the terminology has been in the curriculum since time immemorial, it has not always been used consistently within and among Awarding Bodies, leading to a variety of definitions. To prevent further confusion, and for teachers to have a source of reference for their teaching, The Nuffield Foundation and The Association for Science Education have commissioned a booklet called 'The Language of Measurement' (Campbell, 2010).

Research skills

Research skills, namely the skills involved in reviewing appropriate literature to find appropriate information and/or answer a scientific question, have already been highlighted in various contexts, describing the views of one-third of the teachers. For some of the teachers the requirements seemed to be quite new and they sometimes struggled to guide their pupils to appropriate resources. Teacher H1 described how her pupils "should be much better at that, citation of where they have done the research from, and actually knowing how to do that and write that out correctly" (113-114). She thought the pupils should have been better than had come out in lessons recently, because she felt "communication skills are something that should be embedded through all different lessons and all different subjects" (97-98) which is why she was looking forward to her pupils benefiting from the learning skills training they were going to have during their 'activity afternoons' (see below).

Learning skills

The 'activity afternoons' (see above) are periods which Teacher H1's school was promoting as a way of training their pupils in 'learning skills', which would be "team work, research, using the library, communication, all the different parts like that" (109). This would then benefit the pupils in their being more proficient in skills also required for HSW.

For Teacher G3 "the HSW thing, it doesn't matter what fact it is that you're learning now, the point is it's how you are learning it, and how you can then put it into practice" (86-87). She would say to her pupils:

> "It doesn't matter if the fact I tell you now in fifty years time, when you're a famous chemist, you disprove. The point is, the way that we taught you, and the way that you learnt it, are skills that you can carry on into anything" (G3, 87-90)

Teacher G3 was finding ways to handle pupils' questions about why learn when the 'facts' might not be facts for long, and managed to put a doubly positive slant on it by teaching about the tentative nature of science alongside learning skills.

Critical thinking skills

Critical thinking and the spirit of inquiry to go with it form a set of skills that teachers would like to ingrain in their pupils, alongside inspiring curiosity, and not being shocked that science (and science teachers!) do(es) not have all the answers. Some teachers needed some personal growth in order to be able to allow their pupils to learn the latter, as Teacher I3 noted: "When I first started teaching you felt absolutely mortified to tell a pupil 'I don't know' to a question, whereas now you realise it is OK to say you don't know" (157-158).

One of the aims of the current NC is that pupils should "be able to understand, and respond critically to, media reports of issues with a science component" (Millar & Osborne, 1998, p. 4). Many teachers in this study proved very keen to provide their pupils with the skills to do this. However, a number of them have come to the conclusion that this requires a rather high level of skill.

Teacher I2, for example, has used resources such as Scientific American and the Behind the Headlines website (NHS, 2007-2012), especially with his Sixth Form classes, but thought he could do more:

> "I think that's part of HSW as well in the sense of being able to - and this is a real high level skill, probably don't do this enough and talking to you makes me think I should do this – go and read the Daily Mail, heaven forbid, and actually pull apart an article on the front." (I2, 66-69)

Behind the Headlines provides a guide on how to read the health news (White, 2009), which includes questions that help readers to approach the news with a critical mind-set, and which teachers can use to start this process in their pupils. Teacher B1 formulated his thinking about the development of the high level of skill needed to learn about HSW as follows:

> "Bloom's Taxonomy! That's it! If you look at that, then actually [HSW] is the higher level stuff, isn't it? And the stuff that we want everybody to know! Which is tricky... and actually, by the way, is why some of this stuff can be misunderstood by the low ability kids because they can regard it as a chance to mess around as opposed to a chance to understand what's going on." (B1, 629-634)

One teacher found that it was often difficult enough to get his pupils to think, full stop, never mind think critically. He explained his frustration and his approach:

> "I just find that they don't *think*. I don't know when you learn to think. I do try and let them, I quite like to – I don't quite like it, but... – let them get it wrong. They keep asking 'Sir, sir, is this right?' and I say 'I don't know, give it a go!'" (E1, 783-785)

As mentioned before, teachers use the media in their teaching. The resources are available, and the teachers in this study seemed keen to have their pupils develop the skills required to fulfil the aim of the NC as proposed.

5.3.2 The role of science in education

Science is one of the subjects at the core of the NC and compulsory for all learners between 5 and 16 years old. This means it can, and should, play a crucial role in everybody's education. The interpretation of this role was examined with some of the teachers, as they advanced it in our interviews. Perhaps not surprisingly, next to their ideals most of the teachers weaved 'assessment' into this discussion.

Teacher G1 started from the rhetorical question of "What is the point?" What is the point of science, of physics, at the various levels, compulsory or otherwise? He then went on to answer his own question, starting from the premise that "most of the ideas in [the NC] are turned into sets of facts to be learnt" (273):

> "Now that's not real education, that's learning a set of answers, and it isn't really satisfactory. And since... surely, well, HSW ought to be the opposite of didactic learning, ought to be the opposite of content, we should only be testing those things which we can test in a different way. And yet, when it comes to the students developing ideas, *really* developing ideas, it's not tested at all!" (G1, 276-281)

Teacher G1 would have no objections to the assessment of pupils' ability to produce good quality data, an aspect which is not included in the considerable list of practical skills which are already assessed today. He would welcome the opportunity for pupils to do more individual investigations, on the understanding that "they aren't really going to be developing any new ideas that they didn't know about already" (297-298). He added: "as it stands at the moment, I do think it's so... prescriptive, and it does involve just simply jumping through the hoops" (359-360). This extensive discussion, more extensive than with any of the others, spoke of a mixture of cynicism (acknowledged by G1 himself, see section 4.3.9), idealism and frustration about the mismatch between a good education and a successful assessment system (see also section 6.4.4). We discussed the relative merits of other options for GCSE, but these would have brought other issues, such as more time-consuming teacher assessment, which G1 was not prepared to entertain.

Another long-serving teacher spoke of his responsibilities to his pupils and towards his school, and the potential mismatch between good exam results and what he believes to be a good education:

> "I could get clever students through Biology exams without even considering any of [HSW]. All I would do is pull out questions on MMR and say 'you answer this this time and...' and the other extreme is I could spend hours and hours and hours doing all the educationally good stuff but to no effect or to little effect in terms of getting an A grade in an exam." (I2, 134-138)

'Educationally good stuff', in his opinion, would be: reading articles about new science, learning about drugs trials and case studies, critical thinking, bringing in contexts and everyday applications on top of theoretical science. Teacher I2's remarks are reminiscent of the arguments about rote learning (see sections 4.3.7.4 and 4.3.9).

Teacher D1 would like to see a clearer link between HSW and assessment, or rather she would like to see more appropriate assessment of HSW. This is not because she feels that would bring more teachers to teach HSW appropriately (a sentiment Teacher F1 brought to the fore, see section 4.3.7.4), but because she truly believes HSW is important. She said: "I think the intentions are good but especially by the time it comes to A-level you lose the focus because it is not assessed. It feels to me like a lot of people involved in science education say "oh, HSW, it's very important" but then they push it aside when it comes to exams which is what we have to focus on, so its importance does not come across in the exam system, certainly at A-level." (564-567)

As well as teachers being key players in the intricate business of teaching, learning and assessing, their job does not stop at teaching science and HSW appropriately; they have a role to play as careers advisor as well, as Teacher C1 explained:

> "Kids will make the right decision if they have got the right information and that is the issue that I think that we don't give the information to make their own informed decision [...]. It breaks my heart when I see a very capable scientist going off to do a degree that I know the employment choices at the end of it are severely limited because they didn't have that information about numbers of jobs at the end of it, numbers of graduates in those courses, and there is a whole argument to be had about whether you are honest with the kids about it." (C1, 903-909)

Teachers clearly have ideals and can get quite passionate about certain aspects of their job. HSW seems to have got them thinking afresh about what role they, as science teachers, should play in education.

5.3.3 Learning objectives as starting point

One of the effects of HSW is that teachers have started to build their lessons from learning objectives which do not necessarily contain any reference to scientific content knowledge. Especially for Teacher D1 this provided a sense of freedom she had been longing for (see section 4.2.1). Other teachers similarly spoke of the use of HSW in learning objectives. Teacher G2, for example, said that even at A-level "if there's a HSW section such as relating to the application bit in the textbook, that goes on the board as HSW" (191-192).

Teacher A1 explicitly mentioned planning lessons from HSW objectives: "it usually does have some content in it, but I usually plan it so that I'm not showing progress in that content" (217-218). Completely disregarding progress in content is quite rare, although it may be on the rise (see section 8.4.2), as most teachers "would always sneak some content in there to make sure [they] have got some done" (C1, 318-319).

It does also seem to be dependent on the time of year and how the teacher feels the teaching of certain topics is going, whether or not HSW can (partly) dictate the lesson planning, as Teacher J2 explained:

> "if you are thinking 'oh gosh I have to get through this, this and this on the curriculum' then some of these things, although it's really what it's all about, I am certainly not putting them down as lesson objectives, you are just hoping that it's something that by the way you do things, the way you ask them questions, and the way that you discuss things, that they are going to get the idea of it." (J2, 140-144)

Using learning objectives as a starting point for lesson planning will be discussed further in section 8.4.2.

5.3.4 Progression

Teachers touched on three specific areas where they were concerned with progression regarding HSW: models, theories and skills. The planning for progression through the key stages and relevant courses is considered. In addition, the measurement of progress and the potential for assuring progression through formative assessment is examined.

Teacher E2 referred to a manifestation of the spiral curriculum, where a specific topic is revisited to build on previous understanding:

> "For example when we're talking about models of the atom – I'm thinking about KS5 at the moment – I would talk about the different models, and explain to them... talk about how we change our model and we use the most appropriate model as we're going up the school." (E2, 162-165)

She also hinted at the intricate link teachers see between HSW and content, which is discussed further in section 5.3.5.

Teacher F3 talked at some length about models. He told how you have to be very careful how you present any models to pupils, especially progressively more complicated ones in later years, as pupils' reaction might be "Well you told us last year this, and now you're telling us this" (271). He said:

> "I don't mind that because I tell them from the beginning 'this is the model I'm teaching you at the moment, it's not the be all and end all, because there never will be a be all and end all'." (271-273)

He added that just as much care is needed when a specific new model is presented to pupils, as "you can very soon see the confusion setting in, and the problem is that if you're going to get a new model, you kind of have to disassemble the old model first before you can build the new model" (297-299). Teacher F3 extended his careful reflection to the difficulties that may be encountered with the development of an understanding of 'theory':

> "I think it's a higher-level skill to be able to look and see how scientific theories in more general terms have developed, and develop historically, and therefore I think to begin with, you've just got to get through the idea of what is a scientific theory, how do *you* test it personally, and when they've got that idea, to then start spreading it to a slightly harder concept." (F3, 30-34)

On the progression in the development of certain skills Teacher D3 came to the conclusion that it is best to start as early as possible in KS3 and practise as much as possible. She noted:

> "We don't do this enough, probably. We always complain when they get to A-level, that they can't do presentations very well, or they can't do a debate on the pros and cons of environmental issues, or whatever, because they don't have the skills for it. This is probably... I mean, KS3 is so packed, that probably... it's not done as much as it should be done" (D3, 353-357)

As well as the whole department planning for the teaching of progressively more complicated concepts and the practice and acquisition of progressively more involved skills, planning is required for classes and timetabling, to allow all pupils to achieve their potential. This can cause problems if pupils' potentials are not recognised at the right time, as Teacher C1 explained:

> "Because I am at a point in the year now where I am sat with lists of data for year 8 and 9 and having to make critical decisions about the opportunities that we as a school are going to give these kids, whether they do triple sciences, whether they do core/additional, whether they do a BTEC [Business and Technology Education Council qualification]. In some respects I have to make some of those decisions at the end of year 8 because if they go into the lower band in year 9 they will never have access to triple science." (C1, 858-862)

Progression is intricately linked with assessment. The measurement of progress, especially related to HSW, has caused teachers a certain amount of trouble. Talking and listening to pupils gives them some idea of how they are progressing, and teachers are happy to use their professional judgement to translate these ideas into marks and grades for certain aspects, such as 'how they develop an argument'. However, as for example Teacher I1 noted they "don't have a specific way of judging that" (387). He explained:

> "You do see progression but I don't specifically go out to measure that because in the end, our GCSE and AS- and A-level assessments don't break down the marks into those areas either; you get a grade for chemistry, or biology, or physics, so it doesn't dominate over other areas of development. I'm just as keen that students are numerate. I'm just as keen that they can write chemical equations, and those are equally important skills." (I1, 387-395)

There has been concerted effort to find ways to assess progress related to HSW, and to plan for progression. Although it never achieved compulsory status and its development on a national level has been abandoned, the 'Assessing pupils' progress' initiative, APP, has made an impact on teachers in the region. Teacher D1 was particularly positive about the way it allowed for progress tracking. She thought that

> "without [APP] it is very hard for them to make progress, and very hard for us to tell them how to make progress without those levels existing, but it is impossible to assess and keep records on in the way that was suggested when it first came in." (D1, 434-437)

She was not nearly so positive about the administrative side of it, which was also mentioned on by Teacher F1, who

> "almost felt like [he] was doing this as an exercise for the sake of doing it, like an Ofsted inspector wanting to see what you have been doing but actually it wasn't benefitting the kids, which is ultimately what matters and the time [he] was spending on this [he] could have been preparing a better lesson" (F1, 434-437)

He was in favour in principle, and claimed to have given it "a really big go" (447).

Teacher A1, in a different local area, was also due to abandon the administrative aspect of APP but intended to keep using the principle of 'learning targets', which "shows you what each of the threads is, and it shows you what kind of activity you can do to get to the next level in that thread" (399-401). More details of the benefits of using these learning targets, and a system built around it, are presented in section 8.4.1.

5.3.5 Good practice – separate or integrated

Teacher C1 seemed to be well aware of the requirements of good practice and HSW, as he said "I believe the HSW agenda came out of 'well, good practice is to do this so let's make that the practice we do'" (66-67).

Teacher C3 was adamant HSW needs to be integrated in all teaching. She said it should not be "distinct" (410), but the HSW and content aspects "need to be merged together" (411-412). Her idea of having HSW at the front of the KS4 NC so that it can be used for all of the content was interpreted exactly the same by Teacher E1 who said "it's just 'keep this in mind while you're planning all your other stuff'" (678). Even at school E it was not always like that. Before Teacher E1 joined them, they "very much saw it initially as a bit of an add-on to the syllabus rather than something that was integrated within the whole" (E2, 25-27). It was "gradually, as the exam syllabus changed, [...] it [had] to become more integrated into the whole of what [they were] doing, and [they recognised they had] to start from *that* basis, rather than from the content side of things, purely" (E2, 74-78). Teacher E3 was instrumental in that gradual process, as she "[didn't] think it should be pulled out and taught as a separate thing, because [...] you then lose the whole point of it" (471-472).

Teacher I1 subscribed to similar ideals, but acknowledged that sometimes pragmatism won out. He explained:

> "I think we started off intending to integrate it into our entire teaching scheme but in practice what's happened is, we've taught specific skills close to when students would need to be assessed and we top them up with knowledge prior to an assessment rather than having a more integrated approach across our schemes of work." (I1, 22-26)

Although this sounded almost like a confession, many of the other teachers in the sample would agree that kind of 'topping up' happened in their schools and their classrooms just like Teacher I1 described. Despite this, it can be assumed that different teachers will have strived for and achieved different levels of integration of HSW within their teaching.

Some of the teachers, as mentioned before (see sections 4.2.3 and 4.3.8), were overtly happy to be teaching a course where HSW was fully integrated *for* them, to the point where "you don't particularly know that you're doing it" (B1, 8). For one of the newly qualified teachers having HSW in the curriculum was so 'normal', that she "[found] it quite hard to separate what is HSW and what's not", and it was "only when [she talked] to teachers who've been working for longer, that [she realised] it's a new initiative" (G3, 10-13). In any case, what is important is what the pupils learn from it, and "from a student's perspective, they wouldn't see that as part of... they don't have a section in their folder, or maybe in their head, where they think 'right, I'm learning about HSW now'" (I1, 163-165).

Teacher F3 does not normally like to remove HSW work from the rest – the link with what came before and what comes after, including ethics, is most often needed. He has not participated in the experiment in his school where year 7 received a six-week intensive course of HSW (almost entirely removed from content teaching) at the beginning (see also section 4.3.3), but would do it if asked, as there seems to be evidence within the school that it improved pupils' understanding of HSW. He said:

> "I tend to not do it. But if it was written into a scheme of work as a separate lesson, and it was all part of that scheme to do it, then I would do it. At the end of that year, I would then be able to reflect on how it had worked, and compare it to my usual way of doing things." (F3, 129-131)

He models his own behaviour in this on what he believes scientists do when considering changing their ideas on the basis of evidence, as he explained:

> "Scientists tend to be quite slow to change their ideas because it's their model of how the universe is, and they don't like to change it very much, and so when they do have to change it, [...] it has to be overwhelming evidence before they're willing to change their model." (F3, 258-261)

Around a quarter of the teachers, at some point in our interviews, said something along the lines of "good teachers would...", either in a general sense related to HSW as a whole, or in a specific HSW context. Some of those statements have been presented before for similar or other reasons, but they are shown here to give an overview of how teachers think about good practice:

- "I think that, as with so much, that's the stuff that you get shown in these things, if you're a good teacher you'd be doing these things anyway, without even trying." (B1, 743-744)
- "I think really HSW was how good teaching was done anyway; you shouldn't teach the kids … anything really, unless you are going to put it in a context that makes sense to those children, so good teachers were doing it anyway, I think." (C1, 63-65)
- "As a decent teacher, you want the pupils to be able to take information, and apply it to a situation, so it's something that you would do anyway." (E3, 261-263)
- "Good teaching is good teaching, so if it works with the younger ones, it could work, if you adapted it slightly, with the older ones." (G3, 199-200)
- "We don't have this in our specification so I wouldn't even look and think 'am I doing ICT skills' but I think that is a good teaching practice anyway, I don't call that HSW, and it's something that is taught across the school not specific to Science." (H1, 345-347)
- "I think it's something a good teacher would do in teaching science, is the applications, and the uses, and the relevance; and developing important analytical and research skills, and so on." (K1, 13-15)

The bulk of discussion about good teaching practice was related to the extent to which HSW should be integral to all science teaching, with occasional remarks about specific elements of HSW and how they should be taught.

5.4 Summary

Some teachers clearly recognised the development towards HSW from older versions of the National Curriculum. Teachers' conceptions of the philosophy of science were variable, and could, in places, benefit from more development. Reflections on science teaching showed that teachers were appropriately concerned about the role of science in a good education, and good practice in science education. They thought carefully about progression, and about the learning objectives which should govern their planning. More specific reflection was made of 'skills'.

6 Teachers' reflections on influences on their classroom practice

6.1 Introduction

While the impact on teachers' practice of the increased emphasis on *How Science Works* (HSW) in the curriculum is the main focus of this study, other factors relevant to science education around 2006 have also influenced science teachers' thinking about teaching. A wide variety of influences was brought to the fore, and is evaluated here (research question 2). The data analysis revealed a three-way subdivision of the data regarding influences on teachers (see section 3.7.2). The resulting categories align perfectly with earlier work published by Goodson (2003). This chapter is therefore built on the framework he proposed , which was developed for the study of teachers' change which was not limited to curriculum reform: the *personal*, the *internal* and the *external* agents. Goodson claimed that educational change is more likely to be successful with a strong relationship between those three elements. This chimes with what Harland and Kinder (1997) have also found in their study of the effect of continuing professional development (CPD) on teachers: if value congruence is achieved between a teacher's personal goals in the classroom, the curriculum, and the CPD intervention, it is more likely to effect change than some of the other factors investigated in their study. Value congruence is discussed in section 9.2.4.

Ryder and Banner (2013), in their study of teachers' experiences of curriculum reform at key stage 4 (KS4), considered the following *external* factors: national science curriculum reform, other national or regional school reforms (e.g. to pedagogy or assessment), and accountability measures (e.g. pressures on student attainment via school league tables) (Ryder & Banner, 2013). A variety of factors is directly related to the HSW curriculum itself, which is discussed in section 6.2.1. Change, such as the increased emphasis on HSW in the curriculum, rarely happens in isolation. Other initiatives, for instance a general drive to improve literacy or numeracy skills, may be implemented at any time, when politics or research into good practice demands it. Around half the teachers mentioned factors not directly related to HSW and the science curriculum as influences on their thinking about science teaching, as well as their practice. The effects of other reforms and national influences are presented in sections 6.2.2-6.2.4.

In the context of *internal* influences, Ryder and Banner examined influences on the school as a whole, namely school priorities (e.g. preparation of students for university), the nature of student intake, and the whole school reform agenda (e.g. personalisation of curriculum, assessment for learning); they then considered the influences on the subject department, specifically leadership style and staff working characteristics (Ryder & Banner, 2013). In the current sample factors running across the whole school came to the fore much more than factors within the department. None of the teachers, for example, mentioned anything about departmental leadership, whereas some did mention their school's senior management. Cross-curricular activity is examined in section 6.3.1. School and department development are considered in section 6.3.2. School priorities and student intake are presented together in section 6.3.3, under 'school type'.

Ryder and Banner considered the following factors as *personal* contexts: teaching goals, perceived audiences, conceptualisation of the school subject, teacher subject knowledge and pedagogical skills, professional biography, teacher identity, and goal scepticism among teachers (Ryder & Banner, 2013). In the current study, the teachers advanced their personal biography as much as their professional one, which together are presented here as 'teachers' background and identity' in section 6.4.1. Teacher identity is also included in this section, as researchers investigating teacher cognition have concluded that teacher identity is heavily dependent on teachers' personal and professional background (Phipps & Borg, 2007). As conceptualisation of the school subject was probed together with teacher subject knowledge, these are, along with pedagogy, examined in section 6.4.2. Teaching goals, along with perceived audiences as they are often discussed together, follow in section 6.4.3. Although general scepticism towards HSW did not feature in the current sample, some of the teachers were sceptical about some of the proposed benefits of HSW, which are discussed in section 6.4.4.

6.2 External influences – the HSW curriculum itself and other initiatives

6.2.1 The HSW curriculum itself

HSW is part of the NC, and therefore an external influence within Goodson's framework. Here a number of parameters relating to HSW are of interest regarding influence and change, namely the integration of HSW into all science teaching, assessment of HSW and its effects on teaching and learning, and specific effects of certain aspects of HSW.

One general remark puts the influence of the HSW strand of curriculum itself into perspective:

> "I don't think I've ever met a teacher who has a copy of the NC." (I3, 99)

Teacher I3 was convinced the curriculum would have gone through at least one interpretation by a third party, into a course syllabus for example, before it reaches a teacher. Teacher G1 was also adamant that teachers "work from the specification". He explained: "We tend to feel the exam boards will use [the NC] to create the specification and we are actually interested in – through their filter – 'what do you want us to do?'" (505-507).

Integration of HSW into all science teaching

As shown before, some teachers instinctively took the HSW curriculum to be something that was meant to be introduced and integrated into all of the teaching of science, as one said you have to "read this page, and just keep this in your mind while you have a look at the rest" (E1, 676-677).

As well as online material such as that provided by National Strategies (DfE, 2012c) and Standards (DCSF, 2010a), textbooks have had a recognisable influence on many teachers. Teachers I2 and B1 with their self-confessed debt to SNAB and AQA/OCR TFCS respectively, have already been presented, but there were others who acknowledged that the integration of HSW into their teaching was at least partly due to their textbook providing it so:

> "I think what OCR has over the years tried to do is not for us to see HSW as a tag-on but as part of the learning process, so this idea of 'I have taught this, I have taught that [...], now let's do a bit of HSW' is not what OCR want, they want the HSW to be part of the teaching." (J1, 9-12)

Despite seeing full integration as the ideal way of implementing HSW into teaching, one school has run an experiment of starting their year 7 groups with six weeks of 'pure' HSW teaching (involving very little, if any, emphasis on acquiring scientific content knowledge), and then doing separate HSW/skills exams as well as the traditional tests. The Head of Department acknowledged that "it doesn't quite go with the full flavour of HSW but [...] actually it has told [the department] an awful lot which [they] weren't picking up when it was all integrated" (F1, 391-392). This was an experiment which they intended to repeat to collect more evidence to inform their decision on how to proceed with their KS3 science teaching (see also section 7.4.4).

Assessment of HSW

Teacher F1 clearly recognised the link between teaching and assessment: "It often is the only way to get people to change what they are doing is to assess it; it is sad and it is not the way I think education should work at all, but the reality is that is often what happens" (264-265). Whatever the trigger, teachers have picked up on the increase. Teacher E1, for example, "also noticed on exams [as well as in the coursework] they're asking a lot more about HSW questions" (101). It is not just the teachers who recognised HSW in the exams, "pupils know to expect a HSW question in there, and they will know they can spot them, straightaway; it's just practice makes perfect" (I3, 513-514).

Measuring progress in HSW is difficult (see section 5.3.4), and while the Awarding Bodies have struggled with summative assessment (Hunt, 2011) schools have struggled with formative assessment and their own assessment structures. This led to some separate HSW testing and teaching in one of the schools (see above). Although many teachers were confident that professional judgement is appropriate when assessing certain aspects of HSW, the structured approach of Assessing Pupils' Progress (APP) was welcomed by many of them and one thought "it's a shame that we might be losing [it]" (A1, 560-561).

Problems with assessment drove two teachers to change courses. The situation of Teacher D1 was described in section 4.3.7.2. Her department changed during the course of this study, when GCSE assessment was changing and they decided it was time to leave behind the "awful" (421) coursework of OCR Gateway and change to the AQA Controlled Assessment which, in her opinion, is "much more straightforward" (178-179). The other was Teacher J2 who changed when HSW was introduced into the A-level science subject criteria, in 2008. He explained how the grade boundaries of the exams for Salters Horners Advanced Physics (SHAP) had been "incredibly close" (352) so he had investigated AQA exams and grade boundaries over recent years and had come to the conclusion that they were "better design" (357).

Teacher F1 also experienced problems with levels with KS3 SATs exams. Although he liked the HSW-related questions in the papers, he "felt the HSW questions weren't quite stretching enough, and it seemed they were a level lower than they should have been" (256-258). This aspect of assessment of HSW, regarding a perceived lack of discrimination, is explored further in Section 8.3.1.

Specific aspects of the HSW curriculum

In addition to the emphasis placed on elements of HSW as presented in section 4.3, teachers highlighted some specific aspects of HSW which have had an influence on how they view their science teaching. These are aspects of planning and designing experiments, which have also been described as 'research' (see for example section 4.3.7.2), and the effects of debates and discussions.

The 'ritualistic' use of task sheets to get pupils through their practical work has already been described in section 4.3. However, for example Teacher J2 recognised that "certainly in [pupils'] practical assessments experimental design is a big part of it and the part that [they] find the most difficult, but [he doesn't] tend to think of it as being part of HSW" (253-255). It is clear he incorporated the required aspects of HSW into his teaching, but to him the whole process of a scientific experiment, from planning to completion, is so inherent in the understanding of what science is and the acquiring of scientific knowledge, that he was struggling to see it as a separate part of curriculum which might be labelled as HSW.

Teacher E2, although in agreement that "it's very much about the experimental aspects of it, so designing experiments, and analysing data, and evaluating data" (56-57), was not so sure it plays as big a part at A-level: "the way you teach practical skills at A-level is completely different anyway, [...] because it's much more, certainly in chemistry, training to use techniques correctly rather than designing their own experiments" (290-296). This may be a unique view from a chemist, which adds to the debate of differences which Koulaidis and Ogborn (1989) found in their study of the philosophy of science among biology, chemistry and physics teachers. It certainly distinguished Teacher E2 from Teacher J2 (a physics teacher) described above, and also from Teacher I2 (a biology teacher) who said "despite having been through three years of HSW, [the A-level students are] hopeless at planning an investigation" (190-191). Potential differences between requirements for teaching the different sciences will be explored further in section 8.3.2.

Debates and discussions are not really anything new, as discussed in section 4.2.3, but its implementation rather depends on the confidence of the teacher. Even Pilot Study Teacher T2, who struggled with her confidence in running them, acknowledged they are part of HSW and should therefore be part of every teacher's repertoire. They may not even be exclusive to HSW, but they are essential for pupils to get an understanding of the variety of possible answers in science, and to get their heads round their own opinions, as Teacher I1 noted when asked whether he thought HSW requires teachers to include debates and discussions:

> "There are lots of scientific questions where there isn't a simple answer; there's a lot of science out there where we don't know what the answer is, and it's important that students are exposed to that idea, that there can be differences of opinions." (I1, 349-352)

Discussions and debates are revisited in section 7.3.2.

6.2.2 Literacy

In some science departments a renewed and concerted effort is made to improve pupils' literacy skills in preparation for the longer answer questions in the new GCSE exams coming in for 2011-2012 (see also section 4.3.7). The drive for literacy in science teaching is not new, as Teacher D3 remarked when she talked about the start of her teaching career, around 2000: "KS3 back then was all about literacy and numeracy" (124). However, "particularly with the way Gove is going with the bringing literacy back into science, and making it much more about being able to write", Teacher B1 "think[s] that's going to become more important as we go on" (141-143).

Opinions are divided as to whether it is a science teacher's job to teach literacy. Teacher F2 pondered:

> "We don't ask the English teachers to teach maths, and we don't really ask the maths teachers to teach English, and yet as science teachers we are expected to teach maths, English, science, history..." (F2, 527-529)

Teacher E2 was more confident in her position as a science teacher, perhaps because of her experience, and said: "what you can't teach them how to do, is how to write, or at least *I* can't, I'm not an English teacher; [...] we're very reliant on how they're doing in their English" (427-431, emphasis as spoken). Teacher G3, however, despite (or because of) her lack of experience, was adamant that HSW is the perfect reason for teaching literacy, and much more.

Teacher C1 was not sure that the new GCSE questions were a good idea, especially relative to improvements that had just been introduced in the previous round of changes to GCSE exams, as he felt that "a good nine marks of the entire exam being for being able to write a paragraph" (295-296) was completely out of proportion.

6.2.3 AfL and PLTS

In the period of implementation of the new curriculum including HSW, and in the curriculum period preceding it which saw the emphasis on 'Ideas and evidence', another major initiative reached schools, namely Assessment for Learning (AfL). This was formalised and given a boost through The Assessment for Learning Strategy (DCSF, 2008), based on the work of Black and Wiliam (1998). Although not specific to science, it gives teachers opportunity and a framework to consider aspects of their subject which allow pupils to play an active role in the development of their understanding. This is likely to impact on the teaching and learning of numerous aspects of HSW, as it almost automatically leads to socio-scientific aspects such as peer review. A quarter of the teachers mentioned AfL, or other similarly cross-curricular initiatives such as Personal

Learning and Thinking Skills (PLTS) (Qualifications and Curriculum Authority, 2007b), as confounding variables in deciding whether HSW has influenced their thinking about science teaching and learning, concisely expressed thus: "I'm not too sure if that was HSW or AfL, if I'm honest" (K1, 198).

A remark made by Teacher D3 during the discussion about the potential influence of PLTS and AfL on HSW or *vice versa* put the analysis of influences in perspective: "Either way, as long as we're doing it, does it matter where it comes from?" (280). For the individual teacher this may be a suitable position, but in the light of curriculum development and CPD it is crucial to be able to turn seemingly accidental connections into fruitful interventions.

6.2.4 Ofsted

Assessment culture as it is, and with teachers being so aware of the influence their pupils' assessment has on their teaching, it is surprising that only one teacher mentioned the influence Ofsted had on their practice and their thinking: "I'm more probably influenced by the things that are coming through from Ofsted, to be quite honest" (D3, 260-264). She made general comments about science teaching as a whole rather than specific Ofsted-related activity regarding HSW, but as with the other external factors, it is not always possible to know which factor is influencing which.

Banner and co-workers were equally surprised to find that "[o]ne network institution of which teachers had surprisingly little to say was the schools inspectorate (known as Ofsted" (Banner, Donnelly, & Ryder, 2012, p. 584). They concluded that Ofsted's interpretation of HSW, largely limited to investigative aspects, did not pose any problems to teachers so the influence was not acutely felt. In the light of the current study, this interpretation seems reasonable.

6.3 Internal influences – other school factors surrounding the introduction

6.3.1 Cross-curricular activity

Direct links (or competition!) with other departments can be a source of development of HSW-related thinking and practice. Teacher B1 reported "a running feud with the philosophy teacher at [t]his school because [they] debate over whether the big names in science are as important as the big names in philosophy". He used this to instil an understanding of socio-scientific aspects of HSW in his pupils. He was confident his inter-departmental links led to transferability of the learning. Teacher H1 hoped for the same effect from the 'activity afternoons' her school plans to run (see section 5.3.1). Teacher G3 extended this across the whole school, as she was convinced that "everybody, every subject, every department helps everybody else without even realising it, don't they? They are skills for learning, not skills necessarily for learning science, I think" (608-610).

Especially skills development seemed to be a cross-curricular concern, not always equally explicitly discussed between departments, but relied on by many.

6.3.2 School and department development

Teacher D1 volunteered that "[her] school has a focus at the moment of decreasing teacher talk" (344-345). This gave her an extra impetus to incorporate some new ideas which seem eminently suitable to teaching HSW, such as role play, debates, discussion, and critical thinking.

At School F, where "80% of [the pupils] go on to do sciences at A-level" the science department has its own development plan to encourage pupils to become "not just better exam takers, but actually better scientists" (F1, 610-611). Although Teacher F1 did not expand what he thought it might mean for his pupils to be 'better scientists', it was clear he thought HSW was going to play a major role in that project.

A by-product of a new curriculum worth noting is that school C received some funding because of it, and has therefore been able to obtain new equipment, GPS in their case, that they thought was specifically appropriate to the teaching of HSW.

6.3.3 School type

The uptake and interpretation of HSW varies from school to school, and school type has a recognisable influence. It was a newly qualified teacher (NQT), with recent experiences in a variety of schools, who pointed this out. She added:

> "I almost think that even though this is a selective school, and I was imagining it would be much more didactic, and serious, and like teaching to the exams, this is probably the school that lets the kids ask the most questions" (G3, 456-458)

In this thinking she is backed by her Head of Department, who encouraged his staff to display their individuality, as their pupils expect it, especially regarding answering pupils' questions, and he added: "if it means the rest of the lesson goes to pot, well, it doesn't matter, because you're answering that question; that's important!" (G1, 572-573). He also spoke about the lower ability pupils, even though "of course this is a grammar school, and lower ability doesn't appear here" (411), when he considered the demand of certain aspects of HSW. He claimed:

> "in a sense, prior to A-level, [...] the students don't have enough knowledge to really put together a great deal of argument beyond a couple of sentences; nor are their brains developed enough to be able to put a set of ideas together" (G1, 403-406)

He argued that, especially in the lower school, some aspects of HSW are therefore difficult to teach (see also section 6.4.4).

Perhaps surprisingly Teacher J2, who teaches physics at a Sixth Form college, also commented on the mix of abilities. It is all too easy to assume that A-level Physics pupils have to be of high ability, but his point was that the mix in his classes might be broader than those in schools, as his classes tended to be larger and they allowed pupils in with GCSE grades that a school might not accept for A-level.

Two teachers at KS3/4/5 comprehensive School E contemplated some positive qualities they had come to appreciate in their pupils, and which made the teaching of aspects of HSW easier. Teacher E2 had noticed that the pupils in recent years had increasingly good input in discussions. This counted for "the top groups, and some of the lower ability groups are very much like that as well" (791-792). Teacher E1 concluded that that ability to bring in good ideas was related to the type of pupils they have, which compared favourably in that sense with his previous school.

The teachers who were in the KS3/4 comprehensive schools did not comment on their pupil intake, or the type of school they worked in, or any other factors that might affect their position as science teachers within the school as a whole.

6.4 Personal influences on the teachers

6.4.1 Teachers' background and identity

A teacher's family background is of prime importance. Especially fathers and older brothers played a role for the teachers in this study. Teacher E1 remembered growing up with his Physics teacher father encouraging him to "ask loads of questions, and just to find out stuff" (554). In the case of Teacher B1 it was slightly less voluntary, as he recounted: "I had that drilled into me since forever, literally because of my brothers; [...] they've all studied science, and they were always demanding that you have facts, and that you think scientifically" (530-533).

Nobody relayed any highly influential memories of their own secondary school period regarding HSW, but some links were made with developing views of science at university. Teacher E2, for example, did a Masters degree in Science for Public Understanding, which made her examine her own views critically. Teacher E1 was convinced that he never learnt any of the now required terminology at school. He did remember a course module at university in which he was taught "how to use the units to work out an equation" (529). This is a useful skill in the arsenal of the scientist, which he transfers to his pupils in the name of HSW.

One teacher had a memory of secondary school which was influential in his choice of university degree, if perhaps not in his science teaching. He remembers "a Maths Teacher who was a Physicist but he was teaching Maths, who [...] just went 'not all degrees are equal, mate, and this is the score', because I was deciding what to do" (C1, 632-634). It has meant he takes his responsibility in helping pupils to decide on the next step of their education very seriously (see also section 5.3.2).

The most recognisable impact is that of teachers' own scientific research. Four of the teachers, namely F1, H1, J2 and K1, completed PhD or even post-doctoral research, while D2, G2, I2 and J1 spoke of their experience of Masters' level research, and G2 spent time in industry. All of them have brought some of that background into their teaching, be it very specific aspects such as "members of staff who *haven't* written papers, need to be reminded that scientists in the real world do" (G2, 471-472) or more generally "the practical... the interesting applications of science [which] are what add to what sometimes can be quite dry subjects" (K1, 335-336). Teacher J2 was "quite grateful for having done a little bit of research at some point because [he felt] that gave [him] a better understanding of this process [of doing science]" (483-485). On the other hand, none of them advanced what Ryder and Banner found in the PhDs in their sample: the urge to provide for the scientists of the future, with a single focus on canonical science knowledge (Ryder & Banner, 2013). Some of them most certainly felt the pressure of high stakes assessments (see section 6.2.1), but that did not compel them to limit or direct their teaching. One teacher who did not have a research background was convinced that put him at a disadvantage regarding the teaching of some aspects of HSW, as some of his colleagues, who had worked outside academia before, could give pupils examples of actual research work and how "they've gone through the process" (I1, 197).

There were many more examples of childhood and research-related incidences influencing teachers' views of science and how science works. Teacher C2 is typical:

> "I have always wanted to find out how things work, so I just took everything apart from being a kid and just trying to get that across to other people is probably how I would just say science works, because it does, but it is just trying to prove why it does, that is the fun thing, investigating why things happen." (C2, 370-373)

Questions about maturity of philosophy aside, this exemplified many of the teachers' reasoning for getting into science and becoming science teachers.

Almost all the teachers mentioned some form of training, pre-service or in-service, which had had an influence on their views of science and their teaching of HSW. Some of the influences of teacher training courses on teacher trainees, such as an introduction to TEEP (section 4.3.8) and ways to teach about and through models (section 4.3.4), as well as CASE (section 4.3.8) and Local Authority training (section 5.2.2), have already been discussed.

Teachers referred to a variety of formal courses:

- "I have been for a HSW course with the thought of how to embed it in your lessons at the Science Learning Centre; it was dreadful!" (H1, 13-14) – she claimed she learned nothing new, as the idea of HSW was already fairly clear to her but she had wanted specific ideas for activities in lessons, which was not provided in that course;
- "We have run training in the Assessment Focus strands [of APP]" (C1, 483);
- "It was organised by AQA. They held sort of free training sessions on the new A-level" (J2, 23)

HSW came into Teacher I1's awareness through "information from examination boards" (39). Then, in his department, they "spent staff training days looking at both the assessment criteria and looking at how [they] might change [their] teaching to try and develop the skills within the pupils" (42-45) and "[they] went out as well, to exam board-run training days" (54).

As well as taking part in formally organised training, Teacher C1 did "a lot of research into other schools that were implementing a two-year KS3" to inform his decisions about changes in that direction. Once the news of HSW came, he was ready to press ahead with plans to develop a more skills-based curriculum which he thought appropriate to the implementation of HSW in his school.

Although many of the teachers have had some training in the implementation of HSW into their teaching, the potential need for more is discussed in section 7.4.6.

6.4.2 Growing as a teacher: subject and pedagogy

It is difficult to determine where a teacher's understanding of HSW originates, as it has not necessarily been developed explicitly. As Teacher F3 recognised: "nobody sits down and tells you this is the scientific way, but it's just a diffusion, it's just you picking up the ideas of what science is about" (267-269). Now, with HSW as it currently is in the curriculum, is the time for teachers to make up their mind about how much of it to make explicit to their pupils. This will be explored further in section 7.4.4.

Some teachers acknowledged that they had played down the importance of HSW in the early days, and that their teaching of it had developed only after they had formed an understanding of it for themselves (see also section 5.2.2). Teacher E1 formulated that process as follows:

> "Originally I probably would have been like 'Oh, well you know, that's not too important, [...] I'll do the facts first, and then I might be able to get the HSW things later on." (E1, 233-234)

Some teachers, even of similar age and professional experience, came to teaching with more fully formed expectations of what they were going to do in their teaching regarding aspects which might now be classified as HSW. Teacher B1, for example, was adamant that he "think[s] that is how [he] would want to teach science anyway. It's the correct way of teaching science!" (35-36). 'That' being the way in which he made links between practical work and data and the understanding that developed from those, with the socio-scientific issues connected with the topic under study (see section 4.3.8).

Along with a development of teachers' philosophies comes a development of pedagogy and classroom activities which is not always recognisably linked to a particular intervention such as a curriculum change. Teacher F1 thought that some developments were "just due to teaching and learning moving on and new staff coming in" (362-368). The influence of new staff must not be underestimated. It was also remarked on by Teacher I1 (see section 4.2.3). An example of a new member of staff with fresh enthusiasm would be somebody like Teacher G3, who was keen to share her ideas of developing as a teacher, learning at every opportunity.

In three of the schools, namely D, E and F, teachers noted that "generally things are moving away from chalk and talk, and to something that is more discussion" (E2, 370). Teacher E2 was keen to recount some of the changes she had made to her teaching in recent years, with the proviso that she, as some of the others, was not so sure that it was specifically HSW which had brought her to change, although the changes were appropriate to its requirements:

> "I'll tell you what *has* changed: I would be much more open about kids writing their own notes, instead of expecting kids to copy exactly what I have written on the board." (E2, 371-373)

The confidence to try new things is something that comes more naturally to some teachers than others (see also section 6.2.1). Teacher K1, for example, spoke of various projects he had been involved in which were about trying new elements to his teaching.

There were also teachers who seemed confident in themselves, and keen to try new things, but who were nevertheless looking for some external validation for their ideas and activities. For example, Teacher C1, who had been keen to pioneer changes towards HSW, but who despite that said: "that was nice to know, I suppose, that we were doing something good" (111, see also section 4.2.1).

6.4.3 Teaching goals and audiences

There is one teaching goal which all teachers might aspire to achieve, not just in science departments, but for which many of the teachers in the study felt certain aspects of HSW are particularly appropriate. This goal is to engage and inspire pupils. The other teaching goals which were prominent in the sample were more specifically for a particular audience, such as future scientists.

Engage and inspire pupils

Teacher J1's desire to fire up his pupils by presenting them with various socio-scientific aspects and letting them form their own opinions by means of discussion and debate has already been reported in section 4.3.5. Teacher K1 similarly sought to inspire his pupils by linking science to its relevant applications, and by being creative with his teaching. He recalled:

> "I hope that the students that I teach in the future still have that interest in biology [...]; I've had a few students [...], and they'll say 'I still remember, when you taught [...]'. Yeah, it was one who actually really surprised me; she recited a poem on plant hormones, and word for word! I was just like... 'wow, 15 years down the line!' And 'plant hormones' is not the most exciting thing... haha!" (K1, 372-379)

Other teachers were hoping to inspire their pupils by conveying to them a sense of the wonder of science, and an inquisitiveness, which in many cases they had felt themselves since childhood. Teacher G3, for example, hoped her own enthusiasm was contagious, and thought that "the HSW thing helps you become more [...] inquisitive", resulting in "a childish inquisitiveness that you never really lose, if you're a scientist" (410-412).

Teachers looked for inspiration within science as a whole as well as in HSW specifically, and could not always put a finger on where they had found that inspiration themselves, but inspiring pupils is an important goal for many of them.

Future scientists, better scientists

Sometimes teachers focussed on a particular subset of their pupils when outlining their goals, for example the ones likely to be using science in their working life. Unlike in Ryder and Banner's study (2013), it was not necessarily the teachers with postgraduate research experience and in high achieving schools who were specifically concerned with the higher achievers or the future scientists. For example, Teacher C3 was particularly concerned that HSW should help prepare pupils for their working lives: "I think it makes them better scientists, because they have the skills; I think if it's just content-based, and it's not practical-based, they don't have the skills to then go out into the workplace" (423-425).

Teacher A2, at a KS3/4 school, was clearly concerned with his pupils' preparation for the next stage of their education, and wanted to ensure that they have a good awareness of what HSW means, as he explained: "maybe with those top set ones, who might go on and do some aspect of it in college or in university, they'll actually know what people are talking about when they're going on about this kind of stuff" (587-589).

When considering what HSW might be doing to her pupils, Teacher F2 contemplated the aspect of decision making on the basis of sound scientific evidence, in particular for the pupils who are going to have very responsible jobs such as doctors, of whom there are quite a few in her school. She also pondered competence in manipulative laboratory skills.

Teacher H1, who does have a PhD and works in an independent school and therefore might reasonably be expected to fall into the category of teachers who Ryder and Banner (2013) considered prime candidates for a fairly singular content-teaching goal in which they concentrate on their high achieving potential scientists, was convinced that HSW (rather than content knowledge) was exactly designed to provide a stepping stone to a future in science. She had issues with the assessment of HSW, but was keen to provide her pupils with investigative skills and an understanding of the importance of evidence (see also section 4.3.7.4). She said:

> "I want to actually know [what the benefits of HSW are to pupils], not even to A-level but by the time they get to University and beyond. The whole point of this, surely, is to make scientists of the future and researchers of the future even beyond science; is it actually doing that?" (H1, 403-405).

Although the teachers who taught A-level were asked whether they had any view, and perhaps evidence, of their former pupils' benefiting from what they as teachers would now consider HSW, only Teacher J2 had a positive response. He is one of the teachers who had done postgraduate research, and had been greatly influenced in his thinking about science during that period. He reminisced about the coursework his old pupils used to do for their SHAP course, which he still considered an excellent example of HSW, despite since then taking the decision to change courses due to issues with internal marking. He had had "students that came back and talked about that, they often said 'oh yeah, when we came to do a research project at university, no one else had a clue what to do and I felt like I know what I am doing here'" (492-494).

It is clear from this study that a variety of teachers have the progression of their pupils to post-compulsory science education at heart in their teaching of science and HSW, not merely the ones who have benefited from a long education in scientific research themselves.

Science for all

Teacher A2 advanced a common variant of the utility argument (Millar, 1996) for teaching science and HSW to all pupils of secondary school age in order to increase scientific literacy in the general population, namely that "it does actually impact their lives, and the decisions they make", for example in the context of "getting medical advice" (542-543). He added that "obviously then it's very important for kids that are going to go on and have a career involving science" (545-546). He was covering all his bases, and seemed to be fully behind the intentions of the Core and Additional GCSE courses he was teaching.

For Teacher F2 it was important that all pupils would ultimately understand why she taught them a variety of things under the banner of HSW, because they would get to understand the relevance and importance with time, for example of "why it is important to be accurate and things like that" (598). The word 'relevant' was also used by many other teachers in the sample, in statements about goals and justification of teaching certain aspects of HSW (see also section 7.2.3).

Teacher K1, who taught A-level Biology only, appreciated there is plenty of opportunity for general areas of learning through HSW for his pupils, also the ones who do not go on to study science at university, as he said:

> "I do think if at the end of the year that I've got students who can be given unfamiliar information, a question that they've never seen before, and then see through the science, and be able to apply what they do know, then I think that HSW has worked" (K1, 494-496)

The sentiment of 'science for all' is alive and well, even for teachers who only teach A-level. Teachers are concerned about doing their best for all of their pupils, whether they are the cream of the crop or not.

Other audiences

Two teachers expressed interest in the transition from KS5 to university, understanding the link between their work and that of the lecturers at the next level, and what university lecturers think their pupils should know and be able to do when they arrive at university. One was particularly concerned with the curricular aspect of it, and wondered whether his own teaching was in any way connected to what the lecturers might do. He seemed disappointed that there was little overlap, but he felt it might have to do with specialisation, as he said: "I know a little about a lot, and they know a lot about a little" (I3, 161-162). The other teacher was more concerned with the personal aspect of what her pupils were learning from HSW and bringing to their university course, and whether it is "actually aiding at PhD level or is it something that they have picked up on the way anyway?" (H1, 381-382). Neither seemed convinced that the transition was smooth or that HSW was particularly helpful at the next stage of education after A-level.

Three teachers mentioned parents as an audience. Two accepted, partly grudgingly, that parents' expectations might legitimately influence their teaching efforts as well as their thinking about the curriculum. One teacher taught at a selective school. He said:

> "I don't think that [...] getting accurate results, getting reliable results, reproducible results, the sort of words that are being used there, I don't think there's anything wrong in them getting those good results; I think the average parent would expect their child to be learning how to do that" (G1, 263-267)

He thus argued that the assessment of HSW should include "getting good practical results" (233), which it does not, at the moment. The other taught at an independent school and acknowledged that he did certain things in lessons because he felt the parents might expect it. He explained:

> "what they would be interested in is when I say at the end of the day I can drill them in an ethical thing and I can give them a question and they'll know like little machines to do this, this, this, this, and they'll get full marks. Which is sad but that's..." (I2, 425-428)

A third teacher, at a KS3/4/5 comprehensive school, was also concerned about parents' expectations, on a more personal level, regarding citizenship issues. He was not convinced that all of what is now taught under the banner of HSW actually belongs in the science curriculum, specifically referring to "debating on even using common sense to back up some of their arguments, [when] there are some things where they don't need the science behind it to be able to do it" (D2, 395-396). Nor was he convinced that all parents have appropriate expectations of what schools can achieve. He argued that these aspects belonged in the citizenship curriculum, but that "some of it must have to come from home" (406), and added: "I don't think parents can be completely passive and imagine that school is going to do everything but I know some are" (408-409).

The influences of the 'other audiences' on these teachers seemed to vary from a more professional curiosity regarding the lecturers' influence to a more personal opinion regarding parents' influence, as well as a reciprocal expectation of the teacher towards the parents.

6.4.4 Goal scepticism

Despite the teachers in this study being generally positive about the presence and prominence of HSW in the NC (see also sections 4.2.5 and 7.2.1), there are some specific aspects to it that some of the teachers were sceptical about. These teachers perceived a mismatch between the different levels of curriculum as described by Van den Akker (2003).

Firstly, two teachers advanced the mismatch between the intended and the implemented curriculum because of inappropriate expectations from developers and governmental custodians of the NC towards the teachers who have to implement it. Teacher I3 was sceptical that teaching and learning should be 'fun' and 'challenging' while all the government seemed interested in were the right results and the correct transmission of the interpretation of the Awarding Body's syllabus:

> "So, do [David Cameron and the government] worry about the NC? I just think it's just a token gesture. Essentially what it comes down to, is how the exam boards interpret it, because how they interpret it, you have to teach to that exam. You don't teach the NC, you teach to what OCR says to teach." (I3, 126-129)

Teacher E3 was sceptical that curriculum developers and government ministers really understand what it takes to teach science and HSW under pressure, as she claimed: "A lot of educational theory and ideas about education, and syllabuses, and things like that, are actually forced upon us by people who don't teach, and it does make life difficult sometimes" (433-435).

Secondly, two teachers recognised the mismatch between the intended and the attained curriculum because of inappropriate expectations of pupils' capabilities and cognitive development. Teacher G1 was sceptical that pupils are capable of learning science in a similar way that historical scientists might have learnt it, at the age they are and in the limited time they have at school (see also section 6.3.3):

> "I mean of course the reality is, although we want to think of HSW in terms of great scientists developing ideas over time, the fact is that a 15-year-old isn't a great scientist, and they aren't really going to be developing any new ideas that they didn't know about already." (G1, 296-298)

In addition, he thought "it's a bit of a con to be trying to pretend to students that they're doing some worthwhile research" (323-324), in reference to the perceived goal of pupils carrying out a certain amount of original research in their coursework at GCSE or even at A-level. Teacher E3 was sceptical that pupils are capable of gaining an understanding of the general principles of the development of a scientific theory when it is already difficult enough for them to grasp some of the practical applications of specific theories. She said:

> "I think it's belaboured, sometimes. I think trying to teach a bottom set year 8 about the theories about circulation is nuts! Because you're just about managing to explain that the heart pumps blood around, and they're getting that bit, and then you have to start waffling on about some guy cutting up bodies." (E3, 437-441)

Thirdly, Teacher G1 also advanced a mismatch between the intended (and even the implemented) curriculum and the attained curriculum because of inappropriate assessment practices. He stated that although the NC states that pupils should be taught to collect data, their results are not assessed in any appropriate way. Assessment practices did not match this teacher's goal of a good education in preparation for the next stage of education and life.

These three teachers, E3, G1 and I3, were the most recognisably sceptical from the sample, also by their own admission, and it is not surprising that they brought forward the issues presented. The two issues that Ryder and Banner (2013) found to have caused scepticism in their sample, namely the country's need for more scientists and the goal of scientific literacy, did not feature in the current study.

6.5 Summary

Goodson's (2003) framework of the *external*, *internal* and *personal* agents influencing a teacher has proved very useful in evaluating science teachers' responses to the policy change under study. Some of the external influences, most notably AfL and PLTS, as well as whole school efforts such as the push to reduce teacher talk, make it difficult to disentangle the influence HSW itself has had on teachers. On the other hand, the way all the influences work together may make it more likely for teachers to adopt a change. This conflation of influences and its accumulative potential for a positive outcome, designated the term 'value congruence' by Harland and Kinder (1997), is discussed further in section 9.2.4.

7 Teachers evaluating the emphasis on HSW in the curriculum

7.1 Introduction

As well as the effects of the presence of *How Science Works* (HSW) as a curriculum element on *teaching and thinking*, the teachers considered the emphasis itself, i.e. the prominence and position of HSW in the curriculum, and the influence it has on pupils (research question 3). Some of the arguments from earlier chapters are also relevant here, with a different emphasis.

One of the teachers found a very colourful way to describe his general view of the curriculum balance, namely: "just scientific content without HSW is like a black-and-white photograph versus a colour photograph; you're lacking in detail there" (I3, 557-558). This represents the overall generally positive sentiment of the teachers in the current study: HSW should not go away, as it adds crucial colour to science teaching. Nevertheless, there are some considered arguments about the emphasis of HSW in the science curriculum, both positive and negative.

Some teachers were convinced that it is important to have some separate lessons and perhaps even separate exams for HSW (e.g. Teachers A2 and F1), with others adamant that it is imperative to have it fully integrated, to the point that you do not know that you are doing it (e.g. Teachers B1 and I2). Some were convinced it has had an overall positive effect on their teaching and on their pupils' learning, whereas others were not so sure or even negative about some of it. These and other aspects of the emphasis on HSW in the National Curriculum and A-level Subject Criteria (NCASC) are considered here, starting with a group of positive aspects in section 7.2, then some negative aspects in section 7.3, followed by some views that seem either neutral in themselves, or in which there seems to be a balance of positive and negative, in section 7.4.

The teachers expressed views on several positive aspects of the increased emphasis on HSW in the NCASC, such as its relative prominence, especially in relation to the key stage 4 (KS4) curriculum (section 7.2.1), the changing practice of having HSW-related learning objectives and using HSW as a basis for planning a scheme of work (section 7.2.2), its appropriateness for a variety of pupils in an ever changing teaching climate (sections 7.2.3 and 7.2.4 respectively), and the positive aspects of the influence of HSW on assessment and *vice versa* (section 7.2.5). There were also positive comments about a few specific elements of HSW in the curriculum, which are presented in section 7.2.6 .

On the flip side of teachers who thought that the obviousness of the HSW part of the curriculum was helpful to them, and might be essential for some teachers who are not so confident in their understanding of HSW, were the teachers who felt that it is a shame that some people need it to be so obvious, or to be there at all as a separate curriculum entity. They felt it is part of good teaching, without question, and should not need any explanation or justification through the curriculum. They were, like the others, generally positive about HSW in principle – science needs HSW to be complete – but they felt it should not be separate from or instead of scientific content.

Despite generally positive views of HSW, there are some aspects to its emphasis which some teachers consider negative. One is that there is a fear that scientific content might be lost, which is discussed in section 7.3.1. There are reasons to think that certain aspects of HSW are inappropriate for certain pupils at various levels, which are presented in section 7.3.2. As well as positive views of assessment of HSW as presented in section 7.2.5, there are some negative aspects to it which are presented in section 7.3.3. Some teachers feel that certain specific aspects of HSW do not deserve the emphasis they get, which is discussed in section 7.3.4. Finally there are some teachers who feel that it is time to leave the curriculum alone for a while, to give teachers and policy makers the chance to assess its impact properly (section 7.3.5).

Some of the issues relating to the emphasis of HSW in the curriculum raised either no overwhelmingly positive or negative expressions, or a bit of everything within one teacher's comments, or were such a mix across the whole range of interviews that they fit best in a separate section. One young newly qualified teacher (NQT) made a passionate plea for a balanced view of HSW and content within science:

> "I think the HSW part and the facts or the content are equally important because unless you have got people who are competent in the HSW how do you know that the facts of next year are actually going to be the correct facts?! [...] Like I was saying about the forcing of the graph to go through the origin or whatever: if we had done that since the beginning of time then what we would have now is just a load of rubbish based on someone who

> was trying to fiddle their results. So I think it is really important because the facts of tomorrow are based on the HSW of today if that makes sense!!" (F2, 498-505)

Other issues in this section which were either neutral in themselves or neutral on balance across the sample in this study, were related to progression across the key stages (section 7.4.1), the amount of scientific content required to teach science successfully (section 7.4.2), perceived time constraints at all the key stages (section 7.4.3), the question whether HSW needs to be made explicit or not (section 7.4.4), certain aspects of assessment (section 7.4.5), the need for more continuing professional development (CPD) opportunities for teachers (section 7.4.6), and finally whether or not HSW should be considered a new feature in the NC (section 7.4.7).

7.2 Positive aspects of the emphasis on HSW

7.2.1 Relative prominence of HSW

Some teachers claimed that they have a good understanding of what is required for teaching HSW, and they do not need to have it spelled out to them in a separate (large!) section of the curriculum, while they acknowledged that this might be the best way for others who are not so confident. One said, for example

> "I think it's a pity it has to be separate... I think it is a pity it has to be written down at all to be fair, but I accept that it has to be written down because there are differences in people's ability to communicate science, so that is why the document exists in the first place" (C1, 710-712).

Not everyone put it that strongly, but there were those who contemplated what might happen if HSW statements were removed, for example: "it would be a shame if they stopped being there, because some people might drop [HSW] out, in favour of getting through content" (D3, 140-143). Teacher E2 put her thinking firmly in the context of earlier versions of the NC, where it was "buried in the syllabus and it was always the bit that everyone left out" (704-705), and argued for its separate and obvious position.

Even among the teachers who were generally positive towards HSW in the curriculum, opinions were divided about the relative prominence of it. Teacher C3, for example, was adamant it was wrong to infer from its prominent position a requirement to teach it separately, as she argued:

> "Just because it's first, I don't think it's distinct, it's not *different* from the content [...], it's because each of the different sections [of HSW] should be taught throughout." (C3, 410-415)

This idea, that it must come first but is only first because it is then borne in mind when the rest of the curriculum is considered, was also brought forward by Teacher E1 (see section 6.2.1).

The relative *size* of the HSW part of the curriculum was seen as non-negotiable, because in this way it is compact, self-contained and everlasting, as Teacher G3 noted: "HSW doesn't get expanded or shrunk much more than that page; that is the crib sheet that you can have forever" (561-563). Teacher F1 would agree with the importance of this, leafing through the KS4 NC document and comparing a whole page of HSW (DfES & QCA, 2004, p. 37) to only part of a page of chemistry (DfES & QCA, 2004, p. 38), which "made a lot of teachers sit up and think" (593). He was one of the teachers who thought that others probably needed this message more than himself, and added: "but I think if you try to condense HSW to [a similar size compared to the individual subject content portions], people would hardly touch it [...], so that was one way of making the emphasis work" (602-603). This adds further weight to the initial point about the relative prominence.

7.2.2 HSW affords a new way of planning lessons and lesson sequences

HSW allows for teaching and learning objectives un-related to canonical science knowledge, "[it] really makes you think about what you want them to get out of this lesson" (A1, 319-321). Teacher D1, especially, was really grateful for this change (see section 4.2.1). As also found by Williams (2011), HSW can thus help to answer the eternal question of 'Miss/Sir, why are we learning this?', especially if that is followed by something along the lines of '...if it isn't fact anyway?'. Teacher F1 outlined how the importance of scientific knowledge can be explained to pupils, despite its tentative nature:

> "We may not know exactly how [...] the human body [works], but we can still take the theories we have to develop a new drug that will cure someone of a disease [...], we can develop new materials or whatever and they are a huge benefit to society." (F1, 509-513)

As well as allowing for a fresh look at planning lessons, two teachers claimed that planning through HSW could and should be approached on a larger scale. Teacher C3, for example, thought that “if you’re planning and designing new schemes of work, it gives you a focus, so that you know that all of this needs to run through the content” (404-405). This is an extension of her earlier statement that HSW is not more important than content, but it gives guidance up front on how to approach the teaching of it (see section 7.2.1).

The move towards learning objectives which are not first and foremost about learning canonical scientific knowledge, and an approach to planning which is not led by scientific content, is discussed further in section 8.4.2.

7.2.3 Fit for purpose, relevant and engaging science for all

The teachers appreciated that the curriculum needs to cater for all pupils, of all ages and abilities. They were fully aware that they, as teachers, were partly responsible for educating thoughtful but critical scientists and citizens, and that HSW can help in that. For example, Teacher J1, who taught biology at a Sixth Form College, said: “in the long term I think HSW just creates future scientists because it helps you to question and think” (570-571). In addition, “for those who aren’t going to be scientists we want them to have a better understanding of what science is” (F1, 612-613).

Teacher J1, a Sixth Form tutor, was fairly fixed on the idea of more people becoming scientists, but also saw this more broadly in terms of awareness and appreciation, as he said: “I think it just makes you more aware of science, I think HSW will create more scientists, we will get more people involved in science and we will make more people appreciate science and think more about science” (589-591). It is, however, difficult to pin down the influence of HSW on the uptake of science at A-level and university, as Teacher C1 explained: “whilst we are accelerating constantly and getting more kids to enjoy science, I think their general experience of school and all subjects gets better as well” (744-747). Practical work does not appear to have a positive impact on uptake of science at A-level (Abrahams & Sharpe, 2010), although the authors as well as others have found evidence that a context-based approach, with an emphasis on History and Philosophy of Science (HPS) and socio-scientific aspects, does have such an effect

(Abrahams & Sharpe, 2010; Millar, 2010). Apart from Teacher J1, none of the teachers in the current study, including Teacher B1 who followed this approach, proposed a direct link between HSW and science post-compulsion. Despite this, Teacher F3 thought "it's good that [pupils] have an overview of HSW and the skills involved in it, so they can see science in its place along with all the other subjects, so they get a feel for the subject of science" (405-407). If having HSW in the curriculum helps to inform pupils in the process of their choosing subjects, that is a very positive effect of the increased emphasis.

Some teachers advanced that HSW can be instrumental in the learning of scientific content knowledge. Teacher A1, for example, posed that "you could learn *some* of the science content, but the majority of it you just would not be able to access unless you had these skills" (519-520), which is also an argument for the teaching of skills (see section 4.3.6). She argued: "Unless you can understand what a model is, how can you then understand the content that goes with it?" (547-548). She was also convinced that for the potentially disaffected pupils HSW may provide the extra relevance, as "by going back and focusing more on the skills, rather than the content, we'd get them back on track" (114-116).

Teaching science and HSW is most certainly not just for the benefit of future scientists or the learning of scientific content knowledge. Teachers used a number of phrases to indicate how they feel science teaching should be made appropriate for all pupils: it needs to be *relevant*, linked to pupils' *everyday lives*, science in the *outside world*, it needs *context*. Teacher C2, for example, was convinced that HSW was necessary for pupils to learn any science at all.

Some teachers described HSW as a 'tool' which they use in their teaching. Teacher E3, for example, claimed that HSW "has just been sort of pulled out and said 'here you go' and decent teachers use all sorts of tools like that anyway" (272-273). Teacher B1 said he used some aspects of HSW to build an 'engagement credit' with his pupils, so that "towards the end of term, when you haven't got the time anymore, because you've had them on-side there, you can just crash through stuff" (227-228).

It seems that many of the teachers see HSW as an instrument in the teaching of science. They use it with pupils at all levels, to teach them canonical science but also life skills. It really is considered fit for purpose.

7.2.4 Growing as a teacher

Teacher G3, only in her NQT year, proposed that for a teacher's personal and professional development it can be a good thing to have the flow of teaching year on year shaken up by a revised curriculum or new initiatives, just like it can be refreshing to come across a class or an individual pupil requiring a different way of looking at a particular topic. She was very careful not to step on experienced teachers' toes but was concerned that even they should keep learning and improving, and that a changing curriculum could address that:

> "If you don't flag stuff up like this every now and again, then people would miss the little things. Through no fault of their own! Because teachers are really busy, aren't they? It's not anyone's fault that they might miss something, but a bit of a re-focus every now and again can't hurt" (G3, 591-594)

She was certainly not alone in appreciating the need for continuing development, and the positive influence HSW may have had on that. Teacher I2 acknowledged that "the longer it's been since 2004 the more [he thinks] it's a good thing" (15-16). Time to adopt the change is sometimes all that is needed, as Teacher E3 indicated when asked about her familiarisation with HSW in the curriculum. She responded "it's become increasingly important, hasn't it?" and added "it was kind of wafted at you, and then people walked away and it was never really formally explained; you kind of had to formulate your own idea of what it means" (6-8). Her colleague, Teacher E2, similarly thought that time was an important factor, not just for the adoption itself but also to get away from old habits, as she noted: "Time to develop the strategies to do it, as well; it's easier just to trundle out whatever you always do" (209-210). She acknowledged that she was not always eager to adopt change, and thought she would be equally slow to adopt a change *away* from the current HSW if that ever became a requirement, as she explained: "In an ideal world, I'd retain the best of it, but I think I would probably adjust to whatever the latest fad was, because that's what you do" (587-588).

Time is one of the important factors in teachers' considering of the emphasis of HSW in the curriculum. The time a teacher might take in the normal course of their development to incorporate effective teaching of HSW into their repertoire has been discussed here. Teachers were much more negative about the time scale of curriculum changes in general, which is discussed in section 7.3.5. The time it takes to teach about HSW effectively, over the course of an academic year or a key stage, was a very ambiguous issue for the teachers in this study, which is discussed in section 7.4.3.

7.2.5 Assessment

The emphasis on assessment of HSW was an eagerly discussed issue, with positive as well as negative aspects. Recognisably negative aspects are discussed in section 7.3.3, while mixed or ambiguous views are presented in section 7.4.5.

Teachers thought appropriate assessment was important (see also section 4.3.7). Teacher D1 posed it was not so much certain aspects of HSW being in the curriculum that made a change to how she saw HSW and science teaching. It was the aspect of it being *assessed* that made the real change, for the better, in her opinion, as she explained: "you always felt if you were [discussing ethical issues] you were... not wasting time, but spending time on something that wasn't considered important, whereas now it has been given full focus" (120-122).

Teachers highlighted positive aspects of the emphasis on assessment of HSW at the different key stages.

At KS3, for example, a few teachers mentioned having positive experiences with SATs papers, for example "in those later years, when they started to introduce HSW questions within the SATs exams, they were really good" (G1, 663-665). He remembered a question about "the idea of the time of a swing, and how it depended on length" (666-667), which, through data handling, introduced the ideas of the pendulum and pattern recognition without requiring the pupils having studied them explicitly.

The positive influence of Assessing Pupils' Progress (APP) has been discussed in section 6.2.1. Teacher A1, a proponent of APP in principle despite the amount of administrative work involved, was getting ready to use a new commercial development in assessment at KS3 (Alfiesoft Limited, 2012), where results regarding HSW would be shown separately so that specific feedback might be given to the pupils, in the spirit of APP.

At KS4, Teacher D1 was looking forward to a change in assessment regime, away from OCR's 'Science in the News' coursework towards AQA's ISAs. She explained this would be an improvement, to her as well as her pupils, because it "is thankfully back to the bit of science that has been neglected in a way, which is about planning experiments, writing them up, talking about your data and how good it is" (172-174). With the recent developments in GCSE assessment, Teacher D1 may find that the differences between OCR and AQA are now considerably smaller than they used to be (see section 4.3.7.2).

At KS5 opinions varied considerably as to how much emphasis there is on HSW (see section 7.4.3), but one teacher was very positive about assessment in AQA Biology, where she considered the majority of questions to be HSW, especially data handling. She said:

> "The question might be about a specific test, [...] or a research study [...] about something they've looked at like heart disease, but the exam questions won't ask them about 'what is heart disease?', it'll ask 'what did the tests show, what are the findings?'" (C3, 224-228)

This fits with Teacher H1's statement that you cannot rote learn it because it is *application* of knowledge – not *recall* of knowledge – that is required in A-level biology exams, OCR Biology in her case (see section 4.3.7.4).

7.2.6 Specific aspects of the HSW curriculum

Teachers spoke about specific HSW curriculum parts which may help pupils in their science learning. These are discussed here in the order as they appear in the KS4 curriculum (DfES & QCA, 2004).

Teacher A1, for example, was glad of the emphasis on modelling in the curriculum, as her pupils "got quite a lot out of that" (207-208). The emphasis on modelling as part of HSW was also explored in section 4.3.4. The emphasis on the development of scientific theories, another part of HPS, was highlighted by Teacher G1 as being too important to ignore, as “the children would miss out” (533). He added a caveat about this, which is discussed in section 7.3.4.

Teacher I1 enthused about the opportunities HSW affords for letting pupils do individual investigations. He said his Year 9 class “found it hugely motivating, [...] whereas quite a lot of [the] practical work at other times of the year with most [year groups] is: the students come in, ‘you’re going to do this practical, and the aim is to find out this’” (123-127). He would like to be able to do it with all his pupils, to ask them “here’s an area – what would you like to find out about?” (127-128). Others have also spoken of this desire, and it is discussed further in section 8.3.2.

Teacher K1 was specifically concerned with encouraging pupils’ creative abilities, and was finding ways, through HSW, to help them to improve in this area. He had noted that “sometimes students are reluctant to give an answer in case it’s wrong” (186), which Teacher E1 had also struggled with (see section 5.3.1). Teacher K1 said:

> “that to me is where HSW is important, because for ‘suggest’ questions there is often more than one answer, and there’s valid things that people can say, and if people don’t ask questions, or don’t come up with alternative theories, then it prevents creativity, really.” (K1, 187-189)

He had solved this problem by developing an activity in which “everyone wrote an answer, and distributed them around the class, [...] so there’s a very useful exercise for getting the feedback, so you’re reading somebody else’s answer out, it’s all anonymous” (185-191).

7.3 Negative aspects of the emphasis

7.3.1 Content lost

Some teachers were convinced that certain parts of the scientific content had been lost because of the increased emphasis on HSW in the curriculum. Teacher I2 had had seriously mixed feelings about this at first, but had come to see that it might be for the best. He had two examples of this – the structure of the heart had gone from KS4 and the liver from KS5 – but he now thought, he said, “[HSW] absolutely should be in there” (246). Teacher A2, on the other hand, was not nearly so mellow about the disappearance of organ systems from the OxBox (Oxford University Press, 2012) scheme of work he is following, because he felt it made it near impossible for him to teach the HSW related to it.

Two teachers who qualified after 2006, and cannot therefore be considered able to make a direct comparison between the teaching of the previous and the current curriculum, nevertheless had views about content that might be lost. For one this was most likely due to fond memories of his degree and perhaps his own schooling. He said "[he didn't] like the fact that [...] there's hardly any space stuff because that's the one thing the kids are really interested in" (E1, 577-579). The other contemplated "it is a worry that this HSW maybe pushes out some of the content, because the government hasn't put time in to make both fit in, I guess" (B1, 606-611). His personal views were mixed. He was very much in favour of HSW when considering the needs of all of his pupils, but unsure about the amount of HSW required for further science study. He acknowledged "it's very tricky; it's a balance, isn't it?" (616). This idea of a balance is explored further in section 7.4.

Other teachers were simply frustrated that content was moved around and taken out and put back in again. This was not just a feature of the most recent curriculum change in which the emphasis on HSW was increased. It concerned long-serving Teacher G1 most specifically. He admitted to being cynical about certain changes, and to not always following the curriculum to the letter if he felt it should have been slightly different. Nevertheless, or rather to explain, he said: "But in terms of most of the things that are there, of course we'd agree with them! I mean, they are the bare bones for which the syllabuses are built" (104-105). Another teacher talked about certain aspects of content being put in and taken out and moving around, which drove him to exclaim he "just wish[ed] they would, with specifications, put something in and leave it there" (I3, 247-248). This is explored further in section 7.3.5.

There were teachers who were confident that the scientific content they thought important was still there, but that there was less time for the teaching of it because of the increased emphasis on HSW. They referred not just to the teaching of HSW, but also to the assessment of it taking time that might now not be spent on scientific content. One such confident teacher said: "I always tried to use those skills within the content anyway, so I suppose because you're putting a little more emphasis on it, there's a little bit less time for the science content" (F3, 177-179). His colleague and Head of Department, Teacher F1, had come to the conclusion that APP, although in principle incredibly helpful in assessing HSW properly and successfully, was taking too much time to administer, to the detriment of being able to prepare a good lesson (see section 5.3.5).

There was a variety of feelings towards the perceived loss of scientific content upon increased emphasis on HSW in the curriculum, from frustration, worry and sadness to acceptance.

7.3.2 Inappropriate for certain pupils

Discussions (especially the debating of ethical issues is raised in this context) were generally considered a positive feature of HSW, but teachers sometimes feared that their pupils did not have sufficient scientific knowledge to hold their own in a debate or discussion. Therefore, ethical issues are perhaps better introduced in the later years of secondary school, and might better not be part of the curriculum at KS3. It was particularly Teacher F3 who raised this issue (see also section 5.3.1).

In addition to the requirement of maturity and the development of scientific knowledge before a suitable discussion can be had about ethical issues and other higher level aspects of HSW, Teacher E2 claimed the HSW terminology is "one of the big barriers for a lot of kids, particularly the ones with lower literacy; [...] they can understand things, but they can't describe it using accurate language" (86-90). This has implications for assessment of pupils' progress, as discussed below.

7.3.3 Assessment

There are two issues regarding the emphasis on HSW assessment which a number of teachers recognised as negative. One is that the relative importance of certain aspects of HSW within the assessment is seen as skewed by the influence of certain personalities within curriculum development and the Awarding Bodies, and by factors that are actually measurable, whether or not those aspects in themselves are considered important or interesting. The other issue is that the importance of the use of language has been changed so much that the assessment sometimes seems to be an English comprehension test rather than a science exam. On the interface of those two issues sits the terminology attached to the assessment of investigations, which is a set of terms with very specific definitions which are not easy to understand for all pupils (see above) and which have become important in the measurement of attainment.

Osborne and co-workers were concerned with the operationalisation of HSW statements into "teaching strategies, activities, and material to support their teaching" (Osborne et al., 2003, p. 716). Some of the teachers in this study are clearly concerned about the operationalisation into assessment. Teacher C1 noted: "You are not able to measure the things that really are important and what you can measure becomes important" (125-126). In the mean time, some of the researchers from the aforementioned Delphi study (Osborne et al., 2003) have also been involved with the SCORE project where one of the aims was to do just that: develop an appropriate range of GCSE test items to cover all HSW statements (Hunt, 2011).

Teacher C1 tried to put the measurement in the assessment of communication skills into perspective, and concluded that its importance had become skewed, presumably through the influence of somebody at an Awarding Body. Teacher G1 was also fairly blunt about the sheer unbreakable chain between HSW statement via syllabus to assessment, which he then linked further to what he feels teachers have to do:

> "As soon as you've put that in the syllabus, you've got a set of facts for the kids to learn – if you try to measure students' ability to carry out investigations, you have a set of vocabulary, and specialised vocabulary, and they've got to remember what the word 'precise' means as opposed to the word 'accurate', so you're giving the teachers a set of facts that they're having to teach" (G1, 223-227).

This argument was taken up by Teacher H1 who was not in favour at all of having to teach such specific jargon, and which she was convinced had a very negative effect on her pupils, as "by the time they get to Year 11 they are absolutely sick of ISAs and HSW terminology" (165). She would much rather they were "enjoying understanding what the experiment is about" (169), which might be achieved by asking them questions such as "'how do you make it fair?', 'what is wrong with this experiment?', [or] 'why did it not work?'" (220). She suggested "having longer investigations and time to actually analyse the results and think about why it went wrong" (221-222) and "[didn't] think it is a bad idea to think about researching beforehand and thinking about it more at all, that is good, but having to learn it for exams, it doesn't work" (222-224). She also highlighted a similar jargon-related issue with communication skills in debates and discussions, where, according to her, "you end up just teaching them parrot style 'religious people would be against this'" (68-69).

Two teachers, incidentally from the same school, commented on the amount of reading involved in exams, which are therefore at least partly an exercise in English comprehension instead of an examination of the understanding of science and HSW. Teacher F1 thought it was especially "the section of the communication and applications they don't write particularly good questions on" (229-230). His colleague Teacher F2 was very conscious of her own limitations and how this might cause similar problems to certain pupils. She said: "I am a slow reader and I think when you have got a 30-minute paper I would be quite intimidated by that much writing when I know that I have got another 12 pages to get through!" (413-414). Coupled with the need to interpret graphs and tables which might be included in the text, there is a lot for pupils to take in before the questions are even posed, which requires yet another level of practice of exam technique. The influence of assessment on teaching practice is discussed further in section 8.3.

7.3.4 Specific aspects of the HSW curriculum

Similarly to there being positive views of the emphasis on certain aspects of HSW as discussed in section 7.2.6, teachers registered some factors as negative in this respect. As before, these are discussed in order as they appear in the KS4 curriculum.

The history of science provoked two rather different views. One was that we should not confuse pupils with "ideas that have been superseded", as "there's too much need to understand the way things are *now*, without knowing about what people *thought* they were" (G1, 77-81). Teacher G1 felt that the history of scientific ideas was useful and important for pupils (see also section 7.2.6), "but very much as a background idea" (84). Diametrically opposed to that was Teacher E2's assertion that she loved "looking at how ideas developed historically, and [would] love to be able to focus a little bit more on that" (194-195). She felt that she could not warrant doing that because "it's not one of the main assessment foci" (196-197). Had the emphasis on history of science in the NC been clearer and the assessment more extensive, Teacher E2 claimed she would take the teaching of it a lot further because there was a lot of science understanding to be gained from delving more deeply into it. These two views also add fuel to the debate about the need for explicit teaching and explicit assessment of aspects such as the history of science (see for example section 7.4.4).

Teacher H1's views on the "stupid terminology" (215) involved in investigations have been discussed before (see section 7.3.3). She was the most negative, but she was by no means alone in querying the necessity or consistency of it. Teacher E2, for example, was quite exasperated with the Awarding Body's inconsistent use of the terminology, and queried its necessity in the light of scientists not using it consistently or at all – a complaint that was also heard elsewhere. With the availability of The Language of Measurement (Campbell, 2010) there is no excuse for anybody to misuse or misdefine any of the terminology, and future scientists would benefit from being able to use this terminology correctly, but Teacher E2 does have a point that currently practising scientists tend not to use (all of) this terminology, and their using it is domain- and specialism-specific.

Teachers H1 and E2 also warned to be careful with the amount of discussion/debate that goes on in science lessons. Teacher H1had encountered pupils' negative attitudes towards "silly fluffy stuff [...] as they call it" (439-440), while Teacher E2 claimed to "hate the kind of nebulous discussions about 'who doesn't get the parachute, or who do we throw out of a balloon?'" because, in her opinion, "it's not even a particularly interesting activity, never mind teaching anything useful" (608-610). She referred to an activity in which debating adversaries argue their points with the objective of being saved from being thrown overboard as ballast from an imaginary hot-air balloon. She would much rather do "loads more practical work, and particularly, thinking KS3 here, trying to understand the theory behind the practical work" (613-614). For neither teacher it was the idea of discussing socio-scientific aspects per se which put them off, it was the emphasis on it in their syllabus and in the exam papers.

7.3.5 Time to leave the curriculum alone for a while

Several teachers signalled frustration with quick-succession curriculum changes and related changes to syllabuses and textbooks. Teacher I1 highlighted the latter as a serious financial burden on his department. He would much prefer “a general textbook that would last ten years or more, that had all the chemistry or all the physics or all the biology in, and wasn’t tied to a specification” (7-9). Teacher A2 also raised the point that it is not only the changes to the NC which affect teachers. He really felt “they need to just leave it alone, the curriculum, because since [he’d] been teaching every year there’s been something that’s changed, a new scheme of work or a new… whatever” (367-369). Teacher I3 highlighted one very specific example of the topic of ‘the eye’ which had been in and out of the curriculum as he knew it, and moved around between subjects. He sensed the influence of somebody unknown – a feature highlighted by other teachers in other contexts (see section 7.3.2). He noted: “it’s obviously important to whoever is setting this stuff; [...] well, if it’s got to be studied, just leave it in the same place, and let the same teacher teach it all the time” (257-259). Although this is not a HSW issue per se, the reality of an ever-changing curriculum was disconcerting, and it becomes difficult for teachers to hold on to what is really important, to themselves personally or to what they understand is important to science teaching in general.

Finally, Teacher C1 made a good point about the process of curriculum change not being approached in a scientific manner, with enough time to collect enough evidence to be able to establish whether an intervention has been successful or not. He explained:

> “I mean the overriding issue that causes us problems is the unscientific way that the science curriculum is managed and that is the issue. [...] Surely the way you do it is you set up a curriculum, a system, a NC, a way of delivering science, you set up courses and then you run it for a long enough time to understand fully the effects of that and then you adjust it and you leave that running for long enough to see.” (C1, 775-782)

7.4 On balance

7.4.1 Progression

Regarding progression across the age groups and key stages, Teacher D1 summed up many teachers’ views concisely:

> "I feel it is really embedded at KS3, a bit at GCSE and barely at all at A-level, that it's all there in theory as a nice idea but it doesn't come through in the exams or in the specifications" (D1, 570-572)

This is recognition of a state of affairs, however undesirable. If HSW is to be taken seriously across the key stages, a logical progression should be recognisable, and readily applicable to teaching. As Millar re-stated in his ASE Presidential Address (2012): "As a basis for curriculum design, there is also a huge, and so far unsolved, problem of describing progress in understanding in content-independent terms that make clear what is being learned" (p. 26).

As it stands, at least in part the progression in learning of HSW may not be due to what teachers do, as Teacher D2 recognised:

> "They are getting older, they are going to have more opinions, they have got more life experience – if they are getting better I think it is in a very small part due to what I am doing, a very small part; I think it's more about what they are doing. Yeah, that's food for thought...." (D2, 367-369)

This is not how Teacher F3 would like to see it. Although he recognised maturity had a large role to play in pupils' development of understanding of HSW, he had definite ideas about progression through the key stages, namely that

> "as you get older, the balance should become more about the HSW. But I think to begin with, it's very hard to get some of those ideas. [...] If you don't understand what a scientific theory is, it's very hard to understand how it can develop. So there's got to be a certain level of understanding." (F3, 327-333)

Teachers clearly recognised the mismatch or lack of progression in HSW across the key stages.

7.4.2 Too much content, too little content?

Especially Teacher C1 had a mixed attitude towards the balance between HSW and content, and how the balance should be achieved. He was whole-heartedly in favour of a large emphasis on HSW, as he said: "I think we all know it is the important bit, [...] the bit that affects our lives directly" (584-585). He added:

> "If anything should ever be taken out it's always the content; there are less [sic] things that you need to know and there are always more skills that you need to gain and more ways of understanding, and that is the important thing" (C1, 587-589)

He felt that "content is used as an examiner's tool to see if a kid remembers it" (258-259) which in his opinion resulted in "the most pointless question that comes up year on year in the GCSE Physics sections of the exams, [namely] 'what is the person's job called who takes X-rays?'" (259-260). Although this specific piece of content is not strictly speaking in the NC, it has been taken by the Awarding Body to be a good representation of one aspect of HSW that can be measured readily (see also section 7.3.3), regarding scientific careers.

Teacher C3 also had mixed feelings about the balance between HSW and content but expressed this rather differently, although she would agree with her Head of Department that HSW should be the driving force of the curriculum, as it contains the essence of science learning at secondary school:

> "If [pupils] can't do these… and don't have these skills, then they could be learning *any* subject – these are specific to the way in which you should be thinking about science – so if you take them out, then all they're doing is looking at content, and it could be anything" (C3, 447-451).

These teachers would have argued for looking at and choosing scientific content through the lens of HSW – to include content on the basis of its suitability for learning about HSW (see also sections 7.2.1 and 7.2.2). Millar (2012) claimed that a curriculum solely based on gaining an understanding of the scientific method has never been successful. It therefore seems crucially important to increase the emphasis on other aspects of HSW.

7.4.3 Time constraints

Time constraints were mentioned by teachers of all key stages, and there was as much agreement as disagreement about this, hence its position in this section.

At KS3 some claimed they have more time because of lack of exams. Others claimed the KS3 curriculum is horrendously full, for example, when asked whether there are ever any lessons fully dedicated to HSW, Teacher E3 replied: "if the HSW covers and marries well with [the content as described in the scheme of work], then so be it, but in KS3 especially, there isn't the time" (183-184). Even within the same school opinions were divided as to which key stage allowed for the most extensive and successful teaching of HSW, as Teacher E2 noted KS4 and KS5 have "a lot of content [...] so actually the time to really go to town on the HSW stuff is limited" (311-313). These may have been skewed views because Teacher E2 only had one KS3 group, which she shared with another teacher. Teacher E3 had been responsible for writing most of the school's KS3 curriculum, and had many more KS3 groups herself.

Some teachers were rather blunt in their judgement. Others dressed their concern about lack of time in a wish, like Teacher F2 who "with the older groups would like to be able to spend more time on [HSW] to formally write up experiments" (259-264) as they are still careless in their use of words like 'reliable', 'accurate' and 'precise'. She recognised this flaw in pupils up to around Year 10. Teacher I2 had also recognised that lack of time was preventing him from doing "lots of small investigations [...] in AS like SNAB suggests" (196), which he was convinced explained his A-level pupils' poor planning skills.

Most teachers mentioned the lack of time for HSW at A-level, although they also said that the lack of assessment matched it so beautifully that they were not too worried, as the aspects that were actually assessed had already been developed in earlier years. This observation matches the perceived lack of progression through the key stages (see section 7.4.1).

Some teachers thought there is enough time at KS5 spent on experiments and practical skills, but that there is not really the focus on "that whole wider range of HSW" (F1, 317). Teacher F1 thought this "a pity because there is [sic] lots of things at the higher end that actually we never really look on in schools, everything about the publishing of research and... all that type of thing, it is not really touched on" (318-320), while Teacher D1 claimed that "in the IB [International Baccalaureate], for example, it's very much there" (197-198).

One teacher, at a Sixth Form College, disagreed with the complaints about lack of time at KS5. He felt there was plenty of time to do HSW justice at A-level, as it simply depends on the teacher’s frame of mind. He exclaimed: “To me it’s part of what you do!” (K1, 450). If his example is to be followed, a new approach to planning, through the lens of HSW, may be an answer to the perceived lack of time.

7.4.4 Explicit/implicit

There is a wealth of research evidence that it is imperative to teach HSW explicitly, both to pupils and to teachers (e.g. Abd-El-Khalick & Lederman, 2000; Bartholomew et al., 2004; Monk & Osborne, 1997). It is a logical extension to make explicit what the requirements of HSW are as teachers are meant to teach it.

Especially Teacher F1 was aware of the impact of the lack of explicitness of certain aspects of HSW in earlier versions of the NC. He referred to Sc0 as a precursor to part of it, which, in his memory, was not explicitly taught. He also felt that with certain aspects of teaching “teachers tend to be developing anyway without having to explicitly think about it” (377-378). He was referring specifically to PLTS, but with HSW he acknowledged that in his department “the hope [they] had with HSW was that it was just happening anyway, [...] but it wasn’t” (378-380). As a result of this lack of success in leaving teaching of HSW to develop implicitly, he “[had] become convinced a while ago that [they] needed to have some concerted way of explicitly teaching HSW” (662-663). He therefore started an experiment with the Year 7 classes, teaching a certain amount of HSW separately and explicitly at the beginning of the school year, and testing it separately at the end of that school year. Although he felt that in principle HSW should be totally integrated, he explained:

> “now we know that in an ideal world it is not the way you should do it, it should all be integrated, but we wanted to know ‘Has it worked? Have we made a difference?’ Plus we know we are meant to be assessing HSW as well as everything else and if it is all in together it’s difficult” (F1, 148-151)

Although Teacher C1 commented that it is a pity that some teachers need to be told explicitly what it is about HSW that they are required to teach (see section 7.2.1), he also admitted that it is possible to overlook certain aspects, especially if a teacher is not confident in their own understanding of HSW, so it might be best to have it spelled out.

Teacher D1 was unhappy about the level of explicitness in the translation of the NCASC into exam specifications. Specifically the lack of guidance for teachers about the need to teach an understanding of ethics and the evaluation of secondary sources was a problem. She could see that it would be good for pupils to be presented with unfamiliar information and situations, but felt that teachers needed fair warning of how that might happen, so that they could prepare their pupils. This also represents another example of a mismatch between the intended and the implemented curriculum (see also section 6.4.4), with, in Teacher D1's opinion, considerably negative consequences for the attained curriculum.

7.4.5 Assessment

While teachers' overtly positive or negative views of the emphasis on assessment of HSW have already been discussed in sections 7.2.5 and 7.3.3 respectively, there were a number of instances where teachers talked about assessment with positive and negative expressions together. Some of these were general remarks which apply to all key stages, whereas others were specific to a certain type of assessment.

A general remark was made by Teacher I2, who had grown to like what was required of him with regards to HSW, but was not enamoured with the exams, as he explained: "that's the other good thing about HSW is that whole critical thinking; the trouble is I think the exams let you down when it comes to it" (124-125). Teacher J2 showed a similar ambivalence towards A-level Physics exams, while being in favour of HSW in the curriculum in general:

> "I suppose if it makes people take it seriously and think 'oh well I ought to have something like this in my lessons' I think that is probably ok and that is good; it's always been a case of when it comes to testing students' knowledge of it, it comes across a bit artificially" (J2, 450-452)

Assessment seems to require a balancing act at various levels and key stages. Teacher C1, for example, described the process of applying Assessing Pupils' Progress at KS3, with all five strands (see appendix A) (re)visited five times over two years, which he intended to persevere with even though it was not to become a requirement to do so. This was, in his eyes, still only a compromise in terms of effectiveness compared to perceived need. Teacher E2, when asked whether HSW teaching is limited to ISA work, said: “No, you *have* to include it in the theory as well, because there are, like I said, the QWC [Quality of Written Communication] questions, which I’m sure they put in deliberately to increase the amount of HSW that’s taught” (317-318). Teacher F3 was much more relaxed in his attitude towards assessment, especially at KS3 and regarding the assessment of progress in investigative skills through the level descriptors, which he called “fairly straightforward” (193). He expanded: “with the [other aspects of HSW] it’s very hard – I don’t really make an overt attempt to do that” (195-196). Teachers tended to rely on their professional judgement for assessment of those aspects of HSW which were not easily dealt with through structured testing (see also section 6.2.1).

7.4.6 Need for teacher development

There were teachers who, despite being positive about HSW in the curriculum, may still need more personal and philosophical development themselves, as they did not seem to uphold a modern philosophy of science, for example:

> “I think that the HSW is the backbone of [science] that runs throughout it, and without it you can’t prove a theory, you can’t *prove* things to other people, and show them why something is true in science without knowing how to do [an investigation in a scientific way].” (A2, 525-528)

It was not clear how this teacher envisaged his pupils learning to be critical about evidence, although he would probably argue that is as much part of the scientific way as believing the end result to be true and proven.

Teacher D3 also appreciated the need for more development, regarding HPS especially. In fact, she said “I mean, I’m surprised, myself, by knowing that [HPS] is in there you know, under that banner” (593-594), which she followed with “I’m going to have to look at that myself, in my own time” (599).

Teacher I1 acknowledged that teachers who have a background in scientific research, or extended their experience in some other way, may have been at a comparative advantage when teaching HSW, which he missed out on by going into teaching immediately after his degree. There must be ways, at the National Science Learning Centre for example, to increase such a teacher’s confidence with up to date scientific knowledge. This is what the 'How Science Works: Contemporary Science Conference' (NSLC, 2011) intended to do.

7.4.7 Relabeling

Over half the teachers recognised an element of rebranding or relabeling to HSW, rather than a new piece of curriculum. Teacher A2 came out with it immediately at the beginning of our interview. He said: "although it's been rebranded, it's something that we've always done, I think" (8). He was the only teacher in the current sample who was keen to use the phrase *How Science Works* explicitly with his pupils, while others seemed more likely to keep it low key.

Even some of the teachers who started their careers after 2006, namely Teachers F2, G3 and H1, had a view on 'HSW' as a label. Teacher F2 said:

> "I guess it is like everything else, they have given it a name, it's like the AfL; as far as I know my teachers were doing that the whole time when I was at school, it's just all of a sudden someone has come along and given it a name" (495-497).

Teacher H1 had a rather different opinion, namely that the phrase may not cover its contents appropriately. She said "'the skills to become a good scientist', or something like that, would be better" (364-365). Seeing as HSW covers more than 'skills', this clearly is not a better phrase.

Teacher I3 also contemplated his dislike of the phrase, and whether it needed a new heading at all. He pondered:

> "Philosophy seems to come into Religious Studies, it seems to come into English, and it comes into History and everywhere else; why not call a spade a spade, and say 'this is why we're doing it, it's the philosophy of science'" (587-590)

This clearly causes problems for other aspects of HSW, so this also cannot be considered an improvement.

The longest-serving teacher in the sample came out with a colourful depiction of how he saw the change: “I don’t know. It’s a new label. You know, HSW is a label, it’s a new packaging for the same baked beans...” (G1, 114-115).

Two others did not use the words ‘rebrand’ or ‘relabel’ – they had their own way of depicting how they saw HSW as a heading for a collection of statements, namely:

- “It’s nothing new really, it’s just putting it together as a block, and trying to make more emphasis out of that block” (F3, 55-56, emphasis added)
- “It didn’t have a bracket to put around.” (C3, 43-44, emphasis added)

Similarly to Teacher H1, some teachers were rather negative about the labelling, as Teacher I2 said: “As soon as you label it I think it devalues it for a start” (172-173). He added later: “and that’s why I think science teachers can be turned off by the HSW label because it seems like just something else to do, where actually, if they’re doing a good job, they’ll just be doing it anyway” (476-478). Teacher E3 highlighted a problem with recycling curriculum ideas, when she said:

> “in some ways I think it was... is... something that education suffers from a lot, in that things you already do are suddenly produced as a brand new theory! When in fact they’ve already been there, all that time.” (E3, 16-18)

This is similar to what Millar (2012) warned about, that the science education community must “learn from experience and history: at the very least avoiding ‘solutions’ that have been found in the past not to work, unless we have good grounds for thinking the outcomes might be different now” (p. 25).

7.5 Summary

There is overwhelming support for HSW in the teaching community as exemplified by the teachers in the current sample, which covers a broad range of schools in England, and the majority of opinions about the emphasis HSW enjoys in the curriculum is also largely positive. It clarifies the importance of HSW, which some teachers advanced was perhaps more important for others than for themselves. Where the emphasis was received particularly well, this was almost invariably linked to suitably challenging and appropriate assessment. Teachers would like to see other aspects equally successfully assessed, so that their pupils can get full credit for their understanding of how science works.

8 Related practitioners' reflections on the increased emphasis on HSW in the NCASC

8.1 Introduction

As discussed in chapters 4 and 6 teachers acknowledged that they had been influenced in their practice and their teaching of and thinking about *How Science Works* (HSW) by a range of factors, including textbooks and assessments. Some also mentioned the support they had received from their Local Authority science advisor and through formal continuing professional development (CPD). In order to gain richer understanding of certain influences on teachers' practice, the views of appropriate related practitioners were sought, namely textbook developers, examiners and science education consultants (see chapter 3 for methodological details; two-letter abbreviations (TD, EM and CA, respectively) have been used to distinguish these practitioners from teachers). Where these provide new or additional insights into issues already presented by the teachers in chapters 4, 5, 6 and 7, or where they offer an explanation for those issues, evidence is presented here. Where opinions or insights deviate, these are also examined.

In section 8.2 textbook developers' reflections are presented, followed by examiners' in section 8.3, and consultants' in section 8.4. For each group of related practitioners three sets of reflections are discussed, namely:

1. Reflections on their own practice, in particular where the increased emphasis on HSW has brought changes. Matters such as the influence of publishers, research evidence about curriculum development and the philosophy of courses and course developers are discussed (sections 8.2.1, 8.3.1 and 8.4.1);
2. Reflections on teachers' practice in the light of the changed curriculum, in particular where their own practice may have impacted on this (sections 8.2.2, and 8.4.2). The examiners interviewed did not add any notable insights to this section;
3. Reflections on science teaching in general, especially where their own practice is directly related to this (sections 8.2.3, 8.3.2 and 8.4.3).

8.2 Textbook developers (TD)

8.2.1 Textbook developers' reflections on their own practice

Six textbook developers were interviewed. Three of them, TD1, TD2 and TD3, have broad experience of writing textbooks for a variety of courses and publishers. They put different emphases on the different aspects of HSW. TD1 reported keenness on writing with an emphasis on the socio-scientific (S) aspects of HSW, about what modern scientists actually do, how their science works, "the impact it has on society, and the way real scientists get their ideas" (27-28). TD2 claimed to put more emphasis on History and Philosophy of Science (HPS, further abbreviated to H), through "showing how we know what we know rather than just presenting statements of alleged scientific fact" (100-101). TD3 started the interview by saying: "I think at KS4 you can split the HSW section up into the kind of procedural skills, the experimental and practical skills, and then the issues aspects as well, the societal, economic, ethical kind of things" (4-6), highlighting an emphasis on investigative (I) and socio-scientific (S) aspects.

All three advanced the view that the biggest recent change in their practice was a reduction of autonomy of the textbook author. This has come to the fore especially with the increased emphasis on HSW, as some publishers employ HSW experts for the sections specifically dedicated to HSW. As one of them explained:

> "for example, in the AQA GCSE textbooks, the HSW material is delivered in a separate section at the beginning of the book and is written by people who are HSW experts, shall I say, not by the people who are writing the biology, the chemistry or the physics" (TD1, 9-12)

This practice is by no means limited to the AQA books, nor is it limited to separating out HSW sections. Teachers' guides, practical tasks and worksheets may also be written by different people. Dividing the writing among specialists has become common practice with the publishers of science textbooks in recent years, affecting general textbook authors' modes of working.

Different awarding bodies have different rationales behind their courses. Two of the GCSE course suites, namely AQA Science and the OCR-A Twenty First Century Science (TFCS), are directly informed by research, carried out in Durham and

York/London/Southampton/Leeds respectively (see also Hunt (2011)). The separate section for HSW as it has been implemented in the AQA GCSE Science books has thus been carefully planned, as TD3 explained:

> "So it's a kind of mixture, isn't it, of the chapter that concentrates on it, which gives the theory and philosophy, and the terminology associated with HSW, and then throughout the book, you get the issues, and you also get the procedural aspects of it in practical boxes. So that was the best way, we thought, to deal with it." (TD3, 57-60)

TD3 suggested that "the theory is, you refer back to that chapter, whenever you're doing an open-ended investigation, or whatever, and you need to remind yourself what an independent variable is" (47-49).

TD2 had plenty of ideas on the rationale behind textbooks, specifications and qualifications, and saw

> "two general possibilities. One is that the publishers say 'We want HSW in the textbook.' But more often what they say is 'We want it in the accompanying teachers' resources.' In a way I think that's a better model to follow because it gives teachers a chance to build things in at appropriate places. You can do that, to some extent, in a textbook but it's actually easier for teachers, I think, if it's in worksheets and specific practical guidance and so on" (TD2, 74-77).

TD2 argued it is then up to the textbook author to keep notes for the teachers' pack writers to say "this is a good place to do whatever aspects of HSW" (92-93). As for the inclusion of socio-scientific aspects: "If you're starting a new topic, I always look around for a context to try and give a hook to draw pupils in" (TD2, 146-147). On the other hand, TD2 added:

> "Discussion things are difficult. That is one thing that is very hard to set up in a textbook. People do these things where there's three little heads with speech bubbles all saying different things – I have done it myself as well – but I do think that can be a bit spurious and doesn't really substitute for things coming out of students' own heads. And people need other sorts of resources for that." (TD2, 323-324).

TD4, TD5 and TD6, who are developers of textbooks for context-based A-level courses, felt their practice of writing textbooks had changed very little upon the appearance of HSW in the subject criteria for science. As one of them explained:

> "I think we didn't find it changed the way that we were writing at all, because the nature of the course that we have actually has HSW embedded into it because of the nature of the context-based learning that we have, because of the way we look at how scientists work, and how they contribute, and how the developments are made in thinking in science, it's integrated, and always has been part and parcel of the course." (TD4, 7-11)

TD6 added to this that they "already had something in every single category [of HSW] in the first edition" (56-57). The first edition referred to came out in 2005, before the introduction of HSW into the subject criteria for A-level science. TD6 acknowledged that they "didn't call it HSW but effectively that's what it was" (217-218).

The publishers of the course materials had insisted on an overview in which the specification points relating to HSW were made explicit (for example see Table 8.1). Note that 'skills' were also made explicit in this overview.

Outline and reference to student materials			**Key points**	**How Science Works**	**Skills**
Section 1.1 A space engineer	Introductory article		Self-contained power supplies and temperature control in spacecraft	Applications and implications of science	
Section 1.2 Studying with satellites	Using the Internet and other resources to find information about space missions	Activity 1	Scope and diversity of space research and technology		Use of ICT Study skills

Table 8.1. Summary of the chapter Technology in Space from Salters Horners Advanced Physics (University of York Science Education Group, 2008, p. 349).

The rest of the books from these courses do not contain explicit references to HSW at all. This is part of their philosophy – HSW is fully integrated, as described by TD4 above. TD4 mentioned 'developments in thinking in science', which covers a large part of section H of HSW, and 'the way scientists work and how they contribute', which reflects sections I and S of HSW. The Salters' Institute describes the philosophy of the context-based courses, e.g. that for chemistry A-level, as "an innovative approach to teaching and learning advanced school chemistry in which chemical principles are developed in the context of modern applications of chemistry and the work that chemists do" and claims the course materials include "laboratory practical work as well as group exercises, data analysis, applications of information technology, and so on", which students are referred to at appropriate points (Salters' Institute, 2012). Although the Salters courses were not initially developed with HSW in mind, philosophical and socio-scientific aspects have always been included, alongside investigative and communication aspects which were also prevalent in more traditional courses. The fit, of everything being connected and integrated, is very important to the developers:

> "And I would hope if we've done a good job – you'll have to ask teachers whether we've done a good job – sometimes they wouldn't even spot that it was HSW, but I would hope that they would never stop and say: 'Why are we doing this? There's no need to be doing this here, it doesn't fit.' Because we've done our job badly if that's the case." (TD4, 644-647)

There will always be a worry that leaving any aspect of learning implicit will not raise the required awareness. It is how most teachers have learnt about how science works, but, as TD6 said:

> "I suppose one might worry that – because we've got it completely integrated – even though *we've* carefully thought about it – is it clear to the teachers, all that [HSW] strand that's carefully woven through, and so therefore are they aware of it? [...] Can you pick it up by osmosis?" (TD6, 692-696)

The supplementary material for teachers includes an example of a classroom activity to make socio-scientific and HPS aspects of HSW explicit. It describes a role play of the collaboration between scientists, where, by "the students contributing to the debate [about historical developments towards the understanding of the model of the atom], taking on the role of each individual scientist, they gradually build up the model" (TD4, 186-188).

Development of specific examples of other parts of HSW through curriculum materials can also help teachers develop their repertoire. With respect to ethics, for example:

> "the first time that it was 'a major piece of teaching', we actually presented it in the book, presented different frameworks for ethical discussion and so therefore we're trying to encourage teachers to actually engage with that in a particular kind of way really. Rather than just having a relatively short comment about some of the ethical issues that are associated with the particular context that we're presenting, [...] what we try to do in the way we wrote the resources was to encourage discussion, was to use these ethical frameworks to structure that discussion and give teachers a tool to manage that discussion" (TD6, 123-131)

Although the developers put in every effort to provide the materials to make the teaching as smooth as possible, at least some of them "don't feel it's [their] role to develop [teachers'] understanding of HSW" (TD4, 705). One counter-example to this last point is 'Perspectives on Science' (University of York Science Education Group, 2007), an A-level course about the history, philosophy and ethics of science, where "in the [...] teacher guide there is quite a lot of additional background for teachers and additional resources and references that they might look at and so on" (TD5, 496-498).

Textbook developers (and teachers and other related practitioners) were not influenced by the National Curriculum documents alone. The National Strategies (DfE, 2012c) and Qualifications and Curriculum Authority (QCA) (DfE, 2012d) supported the drive towards good practice in HSW. The National Strategies provided extensive teaching resources for development of effective teaching of HSW (DfE, 2011b). QCA was mainly involved with assessment and examination, but also provided the standards for the QCA/DCSF schemes of work for KS3 (QCA & DCSF, 2009), which included a unit about 'investigating scientific questions'. These efforts had an impact on teachers and other practitioners, as TD3 explained:

> "QCA used to do the assessments; they were people who liked good scientific practice, it wasn't just about testing, they were about good practice. They wrote the QCA schemes of work, and the way they influenced science education, one of the ways, not only by writing their schemes of work for key stage 3 and below, but they also introduced Sc1 kind of questions into their exams" (TD3, 177-182)

In summary, since the increased emphasis on HSW in the NC some textbook developers have had to come to terms with their publishers' ways of dividing up the work which often means the authors are no longer including HSW in the parts they write because 'HSW experts' are hired separately. This is a reflection of the philosophy of the majority of the courses they write for, where HSW is treated as a separate entity to a certain extent. Developers of context-based courses, on the other hand, have not had to change their ways of writing in any drastic sense as they feel HSW had always been integrated in their courses to such an extent that it did not need separate treatment, apart from their publishers' demands to include information indicating where HSW could be found in the course materials.

8.2.2 Textbook developers' reflections on teachers' practice

Most interviewees tended to concentrate on the sections H, I and S from the KS4 NC as described before. Communication, the fourth section, is everywhere in science, and has been in the National Curriculum and A-level Subject Criteria (NCASC) from the beginning. This means that at least for some practitioners it is "taken for granted and not thought [of as] HSW" (TD4, 581-582). When the non-teaching interviewees thought back to their own experiences as a teacher, some quickly acknowledged that 'discussion/debate' is "the thing that probably challenges teachers the most" (TD3, 214). This is something which teachers also highlighted (see for example sections 4.3.5 and 6.2.1) and has caused especially TD2 to reflect on the development of teaching materials in this area (see section 8.2.1). A specific consideration is the need to match debates with the maturity, ability and knowledge level of the pupils, as the following example highlights: some of the other practitioners held the view, like some teachers (see section 7.2.3), that debates without 'proper' scientific content knowledge are pointless. TD1 reported: "more and more people are saying 'I am so fed up of watching or being involved in or coming across knowledge-less debate among students', which actually is teaching them nothing" (361-363). Moreover, pupils themselves have raised this issue:

> "I've had students say [...] 'Do you know, I don't care what somebody thinks if their sister has got cystic fibrosis. I'm not interested. What I'm interested in is what's gone wrong in the genes and what's going on in the proteins. I want to know biologically why. I can think about the other stuff myself.'" (TD1, 394-399)

This is reminiscent of teacher H1 talking about her pupils' dislike of 'fluffy stuff' (see section 4.3.7.4).

8.2.3 Textbook developers' reflections on science education more generally

The related practitioners, like the teachers, were asked about their views of the position and emphasis of HSW in the NCASC. These other practitioners suggested that making HSW a separate entity in the curriculum, however undesirable in its potential pedagogical implications, lends it status and profile. This adds some weight to teachers' expressions of similar views (see chapter 7). TD1 articulated it most clearly:

> "In some ways I don't like the separation of it so much, except that so much of HSW applies to all three sciences and there is a strong sense in which it makes sense to extract the commonality, so that instead of in each bit of the national curriculum you'd basically be saying the same thing in all three sciences. So, from that point of view, I think having it separate is good and I think it is very important that it is high profile." (TD1, 320-326)

While there may be debate about HSW as a separate entity, the feeling that it was not newly introduced in 2006 was common among teachers and others alike, and put succinctly by TD2: "There has been HSW, in effect, in the national curriculum since it started" (TD2, 5-6). TD2 also said, more controversially, that "you can tell from the fact that it's changed over and over again in 20 years that, actually, people don't quite know what it is" (TD2, 170-172). The many changes certainly point towards a searching for the best way to describe and define it, reminiscent of the vast literature concerning Nature of Science (NoS, see chapter 2). This searching extends to a searching for effective teaching and assessment of HSW, which many of the interviewees spoke about.

Some of the teachers, especially J1 and I2 (see section 4.3.5), highlighted how HSW allows for a human side to science, which is important to them. This was also put forward by TD4, who passionately explained:

> "If I was king, I would have much more emphasis on ethical issues. [...] The ethical issues are the bit that tells us where [science] belongs in society, and has a role to play for the better of humanity. [...] And if we're wanting people to be human chemists, then these are the things that are going to do it. It gives that interest value, it gives it the human face, it's not just a calculation, it's a calculation which can actually make a difference to life and death." (TD4, 429-433 and 481-483)

TD4 on the other hand worried that "if you speak to many science teachers at A-level, they will say HSW is not important [and] almost all of the time in lessons is spent on content (153-164)". The evidence from the A-level teachers in the current study, especially those who only teach KS5 such as J1 referred to above but also K1 (see for example section 4.2.1), might allay TD4's fears, as they say they are keen to teach about HSW.

In summary, the textbook developers in this study have highlighted the variety within HSW and therefore potential variability of interpretation, which has had advantages as well as disadvantages for their activities regarding development of textbooks and other teaching materials. Their own philosophy of science and education will certainly have been of influence.

8.3 Examiners (EM)

8.3.1 Examiners' reflections on their own practice

Several teachers mentioned assessment of HSW as instrumental in their emphasis on certain aspects of HSW in their teaching. In order to further inform an understanding of the role of assessment, two examiners were interviewed. This section begins by explaining the practice of developing exam questions, indicating some of the problems examiners have encountered. Practices related to different forms of assessment are presented, and the relationship between specifications and examinations.

EM1 described the general process of producing exam questions, which involves a considerable number of people at various stages, including an independent assessor "who [...] does the paper as though [they] were a candidate [...] to make sure that it works and it's on spec" (314-316). Despite this, both examiners agreed that it is difficult to set good, clear, discriminating testing questions about HSW, and it is forever a work in progress. EM2 "[would] say the answer's often either trivial or very complicated" (301-302). In addition "some of our questions were too easy, and some of the hard questions were possibly 'tricksy' hard rather than science hard" (EM1, 840-841). Occasionally this may have been due to examiners not being given enough training about the requirements of the curriculum, which Hunt (2011) also found. EM1 noted: "that's another new thing for science examiners to learn to do, because we've never had [written argumentation questions] before" (183-184). EM1 would hold that these longer argumentation questions are good for testing understanding of HSW, but that they require a lot of training on the part of examiners as well as teachers and pupils:

> "[We need to] tease out what makes a good answer at different grades so that we can try and help teachers to prepare students better and the examiners to produce a more discriminating mark scheme because some of the HSW questions now will be in these extended six mark answers that we now have. They're ideal for a HSW question." (EM1, 148-151)

EM2 explained how, when their examiners are developing A-level exam questions, they look for opportunities to use an aspect of HSW in every part of every question, and then added:

> "Then we do have to look at each paper and make sure that we are dealing with some of the more complicated ones, which are those ones I've just mentioned. I mean in [our development group] we've got internal rules [...] because nobody tells us exactly what we have to do." (EM2, 185-188)

The 'more complicated ones' referred to are some of the A-level science subject criteria for HSW (see appendix A), which EM2 would like to categorise into groups as follows: "1, 6, 7, and 11, which is to do with what I call models and evidence in science, and 9, 10, and 12, which is science and society" (189-190). This would then mean that "[examiners] have these two areas and [they] make sure that there are questions on each of these areas in each of the papers" (196-197). EM2's groupings are reminiscent of sections H and S of the KS4 NC (see also appendix A). EM2 concluded this argument with:

> " I'd say all the others – apart from carrying out practical work which obviously is only in the coursework – are always covered in all the papers because that's relatively easy to do and it makes for a paper which is balanced in the different aspects of the thing it's asking about." (EM2, 604-610)

EM2's considerations reflect those of the teachers in the study, as well as others: investigation (I) and communication (C) are more commonly and easily included in lessons and more recognisable in assessment procedures, whereas H and S have required more effort both for teachers and examiners. EM2 added:

> "If you can get one that can just be answered by rote that doesn't really contribute much. If you get one where the answer is obvious that doesn't discriminate. But we can tick the box and say we have actually set a question on that particular area of how science works, you see, but that's not really doing anybody any good." (EM2, 307-310)

The HSW statements are somewhat vague, and can thus be interpreted and grouped in many ways. EM2 was rather blunt about this: "a lot of the problems are that these criterial statements aren't worded terribly carefully and therefore you can interpret them as you wish" (75-77). This has some serious implications for the effectiveness of the policy to increase the emphasis on HSW, which will be discussed further in chapter 9.

Several teachers mentioned the lack of discrimination of HSW examination questions, from KS3 to A-level (see for example section 6.2.1). When probed about this perceived lack of discrimination, EM2 confirmed:

> "There is a lack of discrimination. It's not just perceived; it's actual when you look at the data. The questions don't discriminate well. And some of the weaker candidates seem to have a better feeling for it than some of the stronger ones." (EM2, 39-45)

There are also some problems with the controlled assessment which has replaced the coursework from 2011. In fact, EM1 "think[s] that the controlled assessment we have at the moment for GCSE science, [...] is in a bit of a mess to be honest" (33-35). This may be due, at least in parts, to the different approaches different awarding bodies have taken. AQA, for example, is very specific about terminology and requirement for the practical aspect of HSW (Hunt, 2011). The new national criteria for GCSE science say pupils "have got to test a hypothesis, but they don't have to *make* the hypothesis; the exam board sets the hypothesis and they have to devise a way of testing it" (EM1, 768-769). This was a new procedure for EM1, because in their "previous lot of coursework the marks were all for the analysis of the data rather than the setting up of the experiment" (769-770). EM1 insisted that any individual investigation which might be performed in schools is thoroughly tested – "a teacher has tried it out before it becomes a published experiment for an exam for a controlled assessment" (789-790). The coursework aspect of A-level science also varies between awarding bodies. EM2 acknowledged:

> "We have some little things called 'tasks' in AS which... I suppose they do test some of the same things as the written papers really and they test carrying out skills – well that's [subject criterion] number 4, isn't it? – and analysis and evaluation. And most of the other exam boards, I think, just only have that kind of thing. So what we do in A2 is quite unusual." (EM2, 536-539)

'What we do in A2' refers to individual investigations as discussed in section 8.3.2, which requires a higher level of independence from the pupils than most other investigative work in A-level science. All the issues raised here indicate that even for the practical and investigative aspects of HSW, which have traditionally received more attention than the others and which are under continuing development not just because of HSW in the curriculum, opinions are divided on how best to assess them.

In addition to the problems as highlighted by the examiners themselves, some of the other practitioners voiced opinions about assessment which add some weight to one of the findings from this study, namely that teachers felt they can interpret the curriculum change in a way that suits them, partly because of assessment being the way it is. TD2 said: "the whole specification is organised in a way for examiners to be able to examine and not for developing interest or for producing something that will make people want to go onto the next stage or whatever" (TD2, 160-162). CA2 looked at it from another angle, concentrating on parts missing from assessment and therefore played down by teachers: "At the time [development of 'argumentation'] wasn't relevant to [teachers] because the existing exam boards back then paid no reference to that whatsoever, so they picked out the practical enquiry skills and focussed on them" (CA2, 49-51). The assessment focus on practical enquiry skills to the detriment of sections H and S of HSW has been noticeable, not just to teachers.

All awarding bodies are bound by Ofqual criteria for all examinations. Ofqual apply an assessment grid which indicates how many marks ought to be assigned for assessment objectives AO1-AO3, related to the communication of knowledge, the application of skills knowledge and understanding, and the analysis and evaluation of evidence, respectively (Ofqual, 2011). Moreover, they require "so many [marks] at low demand, so many at standard demand, so many at high demand; and you have to have so many marks for maths skills, a maximum number of marks for objective questions, and a minimum number of marks for extended writing questions" (EM1, 319-322). This grid may then be supplemented with other criteria by each awarding body. As a result not only the courses themselves but also the assessment models have turned out quite differently, with varying amounts and types of coursework, practical investigations, and written papers with multiple choice, structured or long-answer questions. For a more detailed study of the assessment of HSW, see Hunt (2011).

'Alternative' modes of assessment were briefly discussed with EM1. Oral assessment methods for instance, however desirable and appropriate for teachers to use for formative assessment, are unlikely to become part of the summative assessment system "because they're very time intensive in school, they're difficult to moderate, and I think there's corruption in those like there is in all coursework" (EM1, 20-21). Another unusual form of assessment was attempted in "the 2006 version [of TFCS], [in] a paper which was called 'Ideas in Context' where there was pre-released material", which allowed teachers and pupils to engage with a larger amount of information than would be feasible during a normal exam. This was done with the intention to "ask about a story that they haven't covered, that isn't in the specification", while avoiding "all sorts of trouble because you have to provide a lot more information" (EM1, 880-884). It was discontinued, partly, as EM1 acknowledged, because it did not prevent the rote learning as had been hoped. Pre-release material has been (and still is) used successfully with some A-level science examinations.

In summary, since the increased emphasis on HSW in the NCASC examiners have tried to find effective ways of assessing all aspects of HSW, to varying degrees of satisfaction both among examiners themselves and the teaching community. Even for the practical and investigative aspects, which have a longer and more recognisable history of assessment, there is no consensus about how best to assess them.

8.3.2 Examiners' reflections on science education more generally

In section 8.2.3 textbook developers' consideration of the status and profile of HSW as a separate entity was discussed as positive, partly because it groups those aspects which are important for all scientists, whatever their specialism. EM2 looked at the grouping and strands of HSW from a different angle, namely that HSW can be subdivided in many different ways, and not all of it is necessarily equally appropriate to all of science, or complete. EM2 would like the statements "to be different for the three sciences; subtly because the three sciences do have different emphases" (EM2, 229-230). As there is evidence that scientists from the different specialisms see their science as philosophically different (Koulaidis & Ogborn, 1989), this seems reasonable, if perhaps ambitious. It may be more urgent at KS5, at which EM2 mainly operates. A-level teachers in this study, however, did not signal this issue.

As it is clear that examiners have been investigating different ways of assessing practical and investigative skills, it is appropriate to highlight some interviewees' remarks regarding individual investigations, such as TD3 who said:

> "What I *would* like to see, I think your last question is about progression, KS3, 4, A-level... I'd love to see at A-level, a project, at least half a term,

> for the kids to do, where they could really do something in-depth, fantastic research, and really feel like they're discovering something; [...] there are problems, but I think the benefits would be fantastic – it would really inspire the students to go on to university then, and study their science" (TD3, 338-343).

Teachers in this study who have experience of just such investigate work, namely those who teach or have taught Salters' A-level courses, were unanimous in their enthusiasm for this aspect of these courses where the benefits to their pupils was concerned. On the other hand, J2 and his department had recently decided to switch to a different course because of the enormous marking burden these investigations caused them. EM2 warned that, while individual investigations have been staple for Salters' A-level courses for some time, they take "a lot of lab time and organisation" (112), and many centres are moving away from them for that reason. This made EM2 conclude that "perhaps the [Salters' Chemistry style] coursework and individual investigation is a way forward although it's not a very popular way forward" (473-474).

EM1 also sounded a word of warning about changes related to HSW and the requirement for CPD: "And it's a message which has come through in the consultation for the new national curriculum [...] – the main report at DfE has said that you've got to bear in mind that if you change things radically then it's going to have INSET implications" (828-831). The report referred to was from a panel of experts commenting on the framework for the new NC (DfE, 2011c). EM1 was not alone in highlighting the need for appropriate CPD relating to HSW (see also section 8.4.1, and section 7.4.6).

In summary, examiners have been active in interpreting HSW in all its aspects in such a way that assessment is appropriate and effective against a background of a philosophy of education in general and science in particular. They are fully aware of the implications for CPD, both for teachers and other users of the curriculum documents, including themselves.

8.4 Consultants (CA)

8.4.1 Consultants' reflections on their own practice

The three science education consultants interviewed supply the teachers in their area with tools, resources and information to enhance teaching, and they are known to team teach and be present in lessons, especially with newly qualified teachers (NQTs). They organise meetings with and courses for teachers. They have also been involved with and/or influenced by the National Strategies (DfE, 2012c). CA1 was adamant that "in the HSW agenda of course there was a large field force of professionals there to support it and develop it through the National Strategies" (38-39). CA2 and CA3 both referred to subject leader development meetings for which "National Strategies produced materials every term; [...] the focus was very much on preparing for the new programmes of study and in particular for HSW" (CA2, 30-32).

CA1 saw their main role regarding HSW as that of a facilitator of teachers' growth and change. Recently, CA1 perceived the need for teachers' development in aspects of philosophy and investigation more urgently than before because of the increased emphasis on HSW in the NCASC, but acknowledged that change can only happen as teachers discover their needs for themselves:

> "Where I'm working the challenge really is I can't tell people what to do, I can hold up mirrors and I can make suggestions but if they don't see a need then it doesn't happen." (CA1, 277-278)

CA3 was more proactive in the development of teachers' understanding of the philosophy of science, starting with Heads of Department, using materials from the National Strategies which are now held at the National STEM centre (DfE, 2009a):

> "Always one of my roles is to train Heads of Science, Subject Leaders, [...] it was about the second session I did when the new curriculum came out and I actually called it 'What is How Science Works?' So we started right back to how have we got to the current thinking in science, so from [...] Aristotle and Francis Bacon, Karl Popper, Kuhn, [...] Feyerabend." (CA3, 60-65)

CA3 "wanted to challenge [teachers'] thinking about what HSW was" (103), and used the National Strategies HSW road map (DfE, 2009b) in CPD sessions (see Figure 8.1 overleaf), to raise awareness and appreciation that science in the real world does not follow the structured format of the POAE (Planning, Obtaining, Analysing, Evaluating) methodology that had been used in secondary school teaching in the recent past.

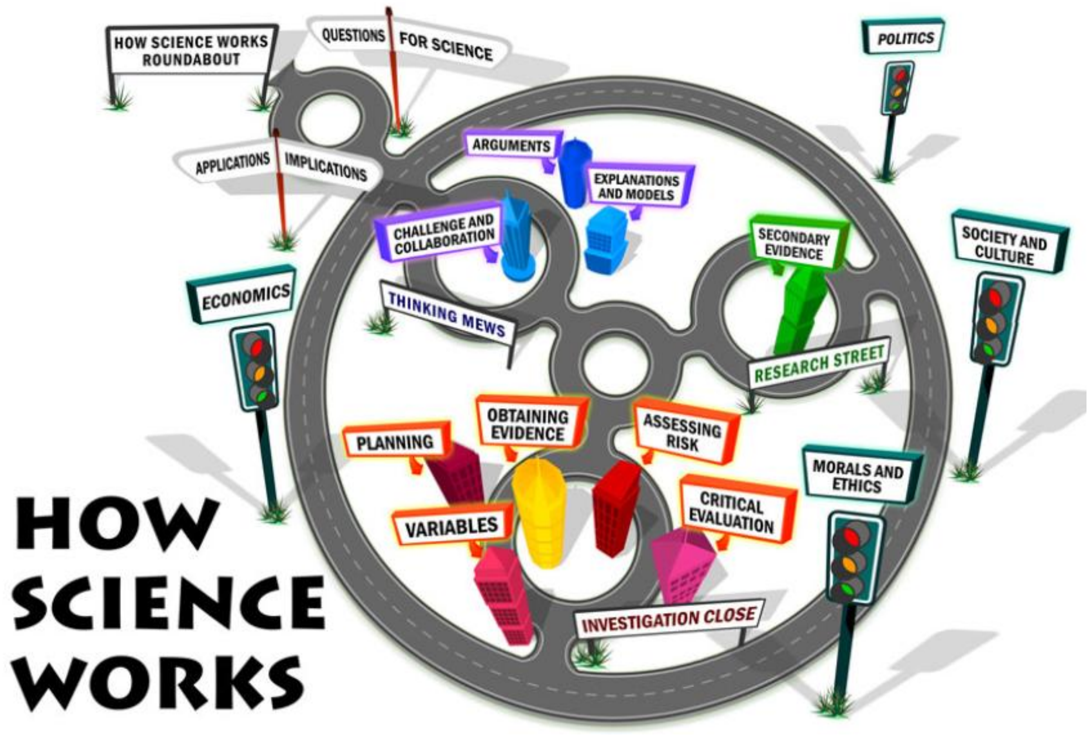

Figure 8.1. ***How Science Works*** **road map (DfE, 2009b)**

In order for other teachers to benefit from CPD meetings, CA2 relied on the cascade mechanism, where "[t]he subject leaders who came, [...] the vast majority of them have taken that stuff back into schools and part of the training that went on on those days was not just pointing things out but giving them CPD sessions to take back with their department" (145-148). 'That stuff', that subject leaders were to take back, were "packages of 'You might want to do this to improve understanding of HSW etc.'" (CA2, 148-149).

The requirements of HSW have led to developments in teachers and teaching materials to improve teachers' understanding of HSW (see for example sections 8.2.1 and 7.2.4). CA2 gave an example of a teacher who had been unhappy teaching about historical development, especially the teaching of the 'wrong' theories. It was only after CA2 helped him to appreciate the tentative nature of science ("actually [the current] theory might be wrong; it's only right for the moment based on the evidence we've got now" (918-919)) that "ultimately he made huge progress in terms of that and that made him a far better teacher" (924).

The status of HSW and its assessment is now such that teachers take note, and might encourage its pervasiveness and integration into all science teaching. CA3 made a passionate plea: "I think if [APP] goes my fear is that teachers won't make [HSW progression] explicit; I think that's the key thing that it did, it started to make HSW more explicitly taught, because it hadn't been prior to that" (378-380). While Assessing Pupils' Progress (APP) was only implemented at KS3, CA3 saw evidence in at least one school where it helped teachers with teaching and assessment of HSW:

> "In one school I worked with [...] the Department were trying to rewrite their scheme of work, in this case it was KS3[...]; we rewrote it linked to using APP and to model what we thought a good [scheme] looks like really, and to do it from a HSW perspective" (CA3, 427-431)

All three consultants acknowledged they were on a mission to make teachers think about their lesson planning in terms of the learning outcomes, and to consider Learning targets (DCSF, 2010b). "The Learning targets came from the National Strategy [sic] but then myself and three other [consultants] got together and turned it into a flipbook" (CA2, 360-361). While this way of planning is not limited to HSW, CA1 added: "I have to say for me I felt my biggest challenge was if I could get teachers first of all to actually plan their lessons around the outcomes, which not everybody does, and to make sure that at least one or a quarter of their outcomes was HSW enquiry skills-based" (890-893).

In summary, since the increased emphasis on HSW in the NC consultants have concentrated much of their efforts on helping teachers understand the requirements regarding HSW, especially in terms of planning their lessons with HSW in mind, and making sense of assessment of HSW.

8.4.2 Consultants' reflections on teachers' practice

Interviewees, both teachers and others, signalled the emphasis on practical and enquiry skills in teaching (and assessment) because the rest of HSW was a lot less clear in their minds. CA2 summarised: "One, there were a lot of similarities with science enquiry, and two, there were a lot of the bits that at the beginning I don't think people thoroughly understood what the extras were" (5-7). CA3, for whom "science has always been about the skills and the process" (26-27), and trying to "fly the flag for scientific enquiry"

(392), expressed worry that "some teachers' understanding of HSW is more linked to KS4 and [...] what appears in the syllabus, [a lot of which] is quite narrow, [...] similar to the old POAE" (22-23). CA3 saw scope for more variety and a much broader view of science in the real world through pupils "thinking[,] acting[,] talking and writing and explaining like scientists" (38-48). HSW clearly encompasses more than scientific inquiry. HPS, communication and socio-scientific aspects of HSW get similar space in the NCASC and assessments, which should see the relative emphasis on the investigative aspects diminish if current developments continue and teachers and others develop their understanding of the requirements of the other aspects.

Scientific content knowledge as taught in secondary school science represents a foundation which is fairly stable. Although this changes only slowly, developments in science in the real world are fast and it is therefore important that pupils learn about the tentative nature of scientific knowledge. In light of this, HSW learning objectives can be more stable and might be encouraged. To CA1 "outcome driven lessons", where "you decide what you want kids to be able to do or to know at the end of the lesson and then you construct your lesson around that", "is a no-brainer" (450-452). CA1 found it frustrating that teachers "don't see [the use of HSW lesson objectives] as part of what they're teaching; [to them,] outcomes have to be knowledge-based, stuff-based. And [these knowledge-based outcomes are] moving and they're moving quickly" (472-477). It is reassuring that some teachers *do* see the utility of HSW lesson objectives, for example teacher D1 (see section 4.2.1).

HSW can be incorporated into science teaching in such a way that it is appropriate for the developmental stage of pupils (see for example sections 5.3.1 and 5.3.4 where teacher F3 argues this issue for two separate cases). CA2 explained how "the [National Strategies] framework looked at both HSW and the 'range and content', and mapped it as a progression in skills across what were called years although they were not tied to Year 7, 8, 9, 10 or whatever; they were steps in degree of difficulty to get teachers to actually develop skills rather than just 'We do it or we don't do it' sort of thing" (34-38). Teacher F3 already has a wealth of experience of teaching across all key stages and has the confidence to adapt the curriculum and a scheme of work to his pupils' needs. Other teachers might depend more on the structured resources which CA2 was referring to.

At times, good practice is developed when needs must, as CA1 noted after visiting a school where they "did an ISA in a day – that was an amazing experience" (948-949), to avoid problems of storage and pupils forgetting or losing important information between sessions. As teacher E1 had come up against these problems (see section 4.3.7.2, where the Investigative Skills Assignment (ISA) is described), this may be just what he needs to introduce in his department.

In summary, consultants respond to teachers' practice as they observe it, if given opportunity. They are deeply involved with teachers, and provide teachers with a wealth of resources and support as needs arise. The HSW strand of curriculum has led consultants to increase their efforts in helping teachers to see science as more than investigating and acquiring scientific knowledge. When not working with specific teachers, consultants can also take a step back and develop more general HSW-related resources, providing a first layer of interpretation of curriculum documents and other materials as they are released.

8.4.3 Consultants' reflections on science education more generally

In line with considerations of progression, and mirroring the definition of skill as discussed in section 4.3.6, the need to practise skills in order to make progress was highlighted by the consultants. 'Skills' and 'processes' are a big part of HSW for many people, as discussed before. It is important to keep in mind that "you can practise a skill and you can get better at it" (CA1, 185-186). This emphasis on practice was also highlighted by two of the textbook developers (TD2 and TD4), though not by any of the teachers. The NC (KS3/KS4) is currently (2013) in the process of being rewritten. Some are not whole-heartedly optimistic about the fate of HSW:

> "The fear is that it won't appear at all per se in the new national curriculum because the focus is very much on knowledge and content and the skills are going to be up to the schools, [...] and I don't think they'll be half as explicit as they were [in the 2004 version]." (CA2, 283-286)

Teachers did talk about the teaching of skills being important. There is support for this aspect of science teaching from previous government (DfES, DTI, HM Treasury, & DfWP, 2003) and the Organisation for Economic Co-operation and Development (OECD, 2011). New curriculum developments seem to have a rather different emphasis.

The skills and processes described under HSW underpin the teaching of the range and content, and the consultants in particular were concerned that the attainment of all of it, including skills, should be on a level for pupils to be considered ready to move on to the next stage of learning science. CA2 drew attention to this levelling being more successful through HSW and APP than with earlier versions of the curriculum:

> "[T]he skill is the underpinning bit. [APP covers] five skills and you have to assess those across Sc2, Sc3, Sc4. So it's not how science works, it's not range and content. It's actually the two together implicitly, because what happened with the old thing was that people came up with a level for Sc1 if you were lucky, they came up with levels for the range and content often from tests; they didn't match up at all." (CA2, 382-386)

Some of the teachers (e.g. A1, see section 6.2.1) were also very positive about the influence of APP on their teaching of HSW in KS3, while its structure has not been taken up at other key stages.

In summary, the teaching and practising of skills relating to HSW was taken very seriously by the consultants, which should stimulate its development by teachers. The form of the new NC may not include HSW as a curriculum element, although teachers and others seem keen to further develop its skills aspects.

8.5 Summary

Related practitioners in this study had two main influences on teachers' practice. One is to provide a first interpretation of the NCASC in textbooks and support materials which teachers use to varying degrees, the other is to develop assessment items which teachers feel compelled to work towards to a large degree. The first is mainly the domain of textbook developers, but the consultants in this study have also played a major role in the development of National Strategies materials which have then been taken to teachers directly or after further interpretation. Both textbook developers and consultants have therefore played a major role in transforming the intended curriculum into the implemented curriculum (Van den Akker, 2003) for teachers. Examiners, on the other hand, have a major role to play at the level of the attained curriculum (Van den Akker, 2003), where teachers' implementation is gauged through the measurement of pupils' learning.

The increased emphasis on HSW in the curriculum has given rise to 'HSW experts' in textbook development, thus removing tasks which some experienced textbook developers saw as an integral part of their authoring. In some cases this segregation of work was a deliberate choice on the basis of the philosophy of the specification, and informed by educational research. In other cases, notably the development of textbooks for context-based A-level courses, the practice has changed very little as the course philosophy was already steeped with HSW-related aspects before the curriculum change happened. While these developments seem philosophically fundamentally different, the experts agreed that the HSW statements as they are in the NCASC happily allow for these widely differing interpretations. This aspect, of interpretation of the curriculum allowing for varying developments, was not limited to textbooks. The examiners and consultants also acknowledged that their practice had been affected by the need to consider their interpretation of what the curriculum required, resulting in experimenting with examination questions and forms, and teaching resources and support, respectively.

Similarly to teachers, the related practitioners displayed a variety of emphases on different aspects of HSW, influenced by their personal philosophies as well as those of the courses or examinations they are associated with. Some, such as AQA's major emphasis on terminology related to investigative aspects of science, have had a recognisably direct impact on teachers' practice. Others, such as the thorough infusion of context-based courses with HSW-related aspects, have been more subtle but equally pervasive.

9 Further discussion and conclusions

9.1 Introduction

In this chapter the findings from chapters 4 to 8 will be summarised and reflected on further, to come to answers to the research questions, and general conclusions about the study.

Section 9.2 will discuss the influences of *How Science Works* (HSW) on classroom practice. Most of the teachers in this study have integrated HSW with all of their science teaching. Some of them gave reasons why they did not integrate all of HSW fully, such as the perceived need for specific lessons on measurements or calculations, for example. Some acknowledged they have experienced the changes more acutely than others, and between them they displayed a variety of emphasis on different factors relating to HSW in their teaching (see section 9.2.2). A useful way to summarise the different responses might be to describe the teachers as somewhere on a spectrum from pioneering, through embracing, following, and reluctant, to subversive (see section 9.2.3). When change is imposed as in the case of a new curriculum policy, teachers have to respond in some way. How they feel about such a change is influenced by a variety of factors. If there is a good match between the individual's view of their practice and the message as conveyed by the policy, a state likened to 'value congruence' (Harland & Kinder, 1997) is achieved (see section 9.2.4). With all these aspects of classroom practice considered, we will then see how far research question 1 can be answered in section 9.2.5.

In section 9.3 the impact of HSW on teachers' thinking about their practice will come to the fore. The increased emphasis on HSW sits in the context of the whole of the National Curriculum and A-level Subject Criteria (NCASC) as well as other factors which influence a teacher's practice. These factors have been presented in chapter 6 based on a framework developed by Goodson (2003) and are summarised in section 9.3.2. A brief overview of teachers' views of how science works is presented in section 9.3.3. We will then see how far research question 2 can be answered in section 9.3.4.

Teachers' views of HSW in the curriculum will be discussed in section 9.4. Teachers were generally very positive about the emphasis on HSW in the NCASC, and advanced a variety of reasons for that positivity. They commonly felt they had some control over how they implement the curriculum for their pupils, whereas they seemed largely resigned to leaving the development of the curriculum to others. The related practitioners in the study, namely textbook developers, examiners and consultants, were more ready to express a view on how the intended curriculum (Van den Akker, 2003) might be developed. In section 9.4.2 some positive opinions about the increased emphasis on HSW are brought forward, followed by other outlooks in section 9.4.4. We will then see how far research question 3 can be answered in section 9.4.5.

The remainder of chapter 9 will be concerned with other aspects of the study, not directly related to the research questions. In section 9.5 a critique of the study will be presented. The instruments used, namely interview schedules, performed well. Some other aspects of the strategy and techniques employed for the study are examined here for their performance. Next, implications of the research and ideas for further work will be discussed in section 9.6. The chapter will finish with overall concluding comments in section 9.7.

9.2 Influences of HSW on classroom practice

9.2.1 Overview – addressing research question 1

Research question 1 asked:

How does *How Science Works* influence science teachers' classroom practice?

> What do they do now that they did not do when HSW was not in the curriculum? Is there something they would not do if it was not for *How Science Works*? How do they feel about that?

The teachers in this study felt the need to respond in varying degrees to the increased emphasis on HSW, and it is therefore useful to group them according to how they reported their change level: "changes-certainly", "doing-already" or "doing-some-already-but". Different aspects of HSW – grouped as before and abbreviated H (History and Philosophy of Science), I (inquiry), S (socio-scientific) and C (communication) – received varying emphasis from each participant in the study. This, and a number of other factors such as reliance on others for a first interpretation of the curriculum documents, resulted in a variety of emphases in practice (see section 9.2.2).

In addition to characterisation according to their reported change level as just recounted, the teachers with experience from before the new curriculum can be categorised on the basis of their approach of the change itself. The teachers' readiness to change can be described as lying on a spectrum from pioneering, through embracing, following, and reluctant, to subversive (see section 9.2.3).

From some of the teachers came the sense that change can be a good thing in itself. When the policy for change matches the values and beliefs of teachers, they are likely to implement it. In cases where a need for change is not so instinctively felt, teachers ask for evidence to be collected and presented to them, or for time to collect this evidence themselves (see section 9.2.4).

Summarising the findings from chapters 4 and 5, and drawing them together in the context of the literature reviewed in chapter 2 with additional findings from related practitioners as reported in chapter 8, section 9.2.5 will present answers to research question 1.

9.2.2 Variety in emphasis on different aspects of HSW in classroom practice

By their own admission, not all teachers in the study felt they had changed their practice because of the increased emphasis on HSW. Of the ones who felt they had changed, only around half admitted to this readily. This latter group can be classified as having implemented "changes-certainly", while the former were adamant they were "doing-already". The remainder were "doing-some-already-but" they acknowledged they had also implemented some changes. All the teachers in the study, including those who started teaching after the 2006 curriculum change, talked about certain aspects of HSW more than other aspects.

From the first National Curriculum (NC) 1989 onwards, the aspect of investigative science (I) has been at the forefront of teachers' minds, as its position has been clearer compared to the other aspects, notably H and S. Despite this, the other aspects of HSW receive attention in science classrooms, as was evident from the observed lessons, and teachers discussed these aspects freely, sometimes animatedly and passionately. It was only the aspect of communication (C) which teachers were surprised and sometimes even apologetic about during the interviews as it was deemed so obviously part of science that it might not warrant explicit discussion. Judging by the observed lessons, communication (and not just verbal aspects) is very much part of science teaching and learning.

The differences in emphasis on the different aspects of the HSW strand of curriculum (specifically H, I and S) are resulting from:

- redefinition of what was already done (e.g. Teacher G1, see section 4.2.2);
- cherry-picking to suit either the teacher's or the pupils' needs (e.g. Teacher E2, see section 4.3.3);
- recognition of emphases in the examinations on certain aspects more than others, for example data handling being more thoroughly and successfully examined and therefore requiring and receiving more attention in teaching than a question like "why is it important to test theories by experiment?", which some perceive to need no more than common sense (e.g. Teacher B1 (see section 4.3.7.2) and Teacher J2 (see section 4.3.9), respectively);
- reliance on commercial curriculum materials (textbooks, revision guides, teacher notes) as the foundation for lesson planning. This means there is usually at least one extra level of interpretation of the intended curriculum (Van den Akker, 2003) before the teacher implements it (e.g. Teacher I3, see sections 4.2.3 and 6.2.1);
- commitment to a particular exam specification and/or certain textbooks
    - AQA teachers are recognisable for their emphasis on terminology related to investigations; other practitioners confirm the need for this emphasis, and the philosophy behind it (e.g. Teachers E1 and F1, see section 4.3.3 and developer TD3, see section 8.2.1);
    - Twenty-First Century Science (TFCS) (GCSE) and Salters' (A-level) teachers describe the way the course integrates HSW to such an extent that you hardly know you are doing it; other practitioners confirm that this is part of the philosophy of the course (e.g. Teachers B1 (see section 4.3.8) and I2 (see section 4.2.3), and developer TD4, see section 8.2.1).

The main reason one teacher advanced for putting an emphasis on ‘skills’ was the dissatisfaction with the status quo and a vision of what was required in its place (Teacher C1, see section 4.2.1).

Avoiding the teaching of certain aspects has a variety of reasons, such as the opinion that anecdotes are enough (e.g. Teacher G1, see section 4.2.2). Another is the deep discomfort with the classroom management of an activity which seems required, such as ‘discussion’. This was most acutely felt by Teacher T2 in the pilot stage of this study, but others referred to similar problems. Developer TD2 also acknowledged it from their own teaching experience, as well as admitting that discussion and debate are very difficult to provide good resources for (see section 8.2.1).

9.2.3 A spectrum of readiness to change

The teachers in this study not only showed variability in their practice and their acknowledgement that change had happened, but also in their approach to change itself, resulting in a *spectrum of readiness to change*. Some saw in the curriculum development around 2006 a validation of the *pioneering* process they had embarked on in recent years. Others had become dissatisfied with the curriculum, recognised opportunity when the new one arrived in 2006, and *embraced* the changes immediately. Yet others needed a little more persuading and simply *followed* the top-down implementation as deadlines to do so approached. To complete the spectrum, reluctance and even subversion must be expected. In this study, however, these attitudes were rare, and limited to detailed aspects rather than recognisable overall traits.

It is useful to make a visual representation of this spectrum to get an overview of the teacher participants’ attitudes to change. Figure 9.1 (see overleaf) provides such an overview, giving as much information about the teachers as possible without overloading the image. The teachers who had started teaching before 2006 are assigned a position along the x-axis, the spectrum of readiness to change, on the basis of their assignment in chapter 4. Their position along the y-axis depends on the length of their teaching experience. Their gender is indicated by colour, and their subject specialism by a superscript. Three of the teachers, namely E3, F3 and G1, notably displayed some subversion while being generally positive about HSW otherwise, and have been assigned a second, fainter, position in the S-area of the chart in addition to their more general position further to the left.

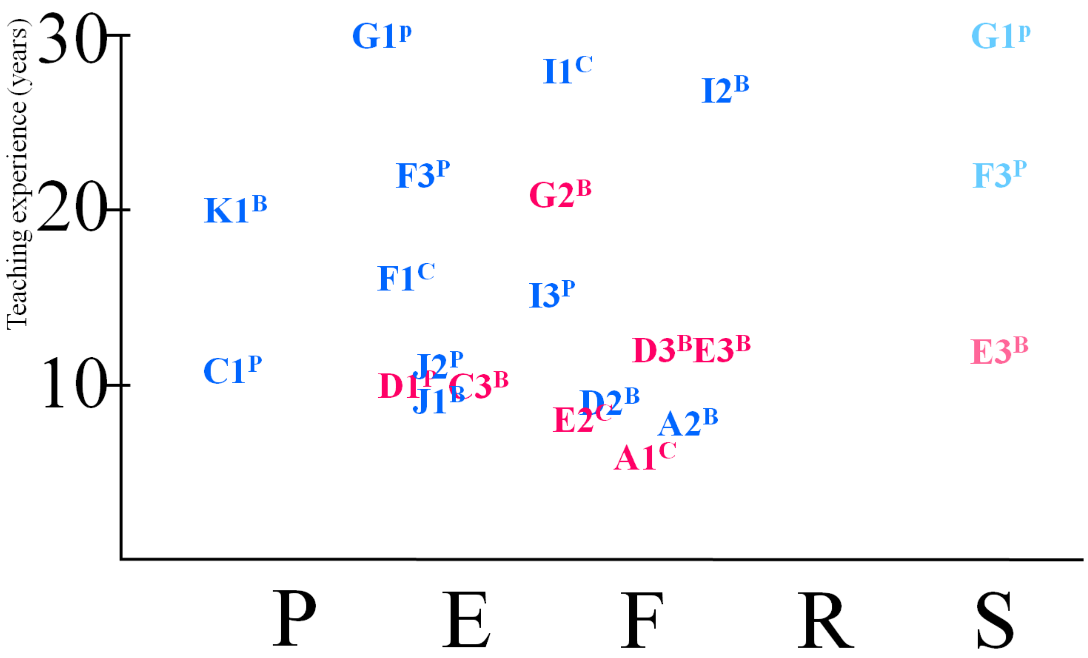

Figure 9.1. Overview of the teachers' length of teaching experience vs. spectrum of readiness to change; P = pioneering, E = embracing, F = following, R = reluctant, S = subversive. Superscripts denote subject specialism (B = Biology; C = Chemistry; P = Physics). Gender is indicated by colour (blue for male, pink for female).

The sample is too small to draw general conclusions, and there is no evidence of a link between length of teaching experience and viewpoint on HSW. The chart does, however, give a good indication of the wide range of positions the teacher participants held. This strengthens the view that the sample covers the broad range of the whole teaching population. The spread seems similar for male and female teachers, although there were no pioneers among the females. The limited data do not allow for a gender effect to be explored but there is no reason to assume there is one. There also is no recognisable pattern according to subject specialism.

Teachers G2, I1 and I2 were the most problematic to assign a single position in the chart. Especially I1 and I2 had obvious characteristics of more than one area of the spectrum, and G2 seemed to lack confidence but felt compelled to do what she felt was required of her. Teacher C1 was one of the most obvious pioneers, and all the more so for his relatively short experience.

In this study, none of the participants currently displayed overall reluctance with respect to teaching aspects of HSW. There may have been elements of reluctance in some of them initially, about which only Teacher I2 was explicit, but this was no longer evident at the time of the interviews.

All-out subversion was also not seen in the participants in this study. It occurred perhaps only in the form of refusing to teach certain aspects of HSW to certain pupils as they were not mature enough, or in the form of persisting with the teaching of a certain amount of content knowledge because a topic felt incomplete without it, which has to mean less time for HSW. This part-subversion applies to Teachers E3, F3 and G1, who are highlighted in paler colours on the right hand side of Figure 9.1, in addition to their more appropriate overall positions towards the left of the chart.

There are possible reasons for the generally positive attitude towards the change, and the absence of participants with an overall negative view, such as:

- It is a self-selected sample, made up of volunteers only, and volunteers are generally positive towards the research process and the research topic(s). Some participants, however, were approached personally and directly, which means that they were put under more pressure to participate than others. This could result in more frankness as well as more friendliness and therefore probably does not affect the overall picture. Some others had been volunteered by their Head of Department, and there is no explicit data about how voluntary they themselves were. This applies most strikingly to Teachers C3, F3 and G3. C3 and F3 both referred to being volunteered during the interviews, and G3 was volunteered in the presence of the researcher. C3 displayed a small amount of impatience at times during the interview, but nevertheless provided considered opinions and good quality data, with no overall negativity. F3 seemed very confident in his position in his department and displayed an overall positive and considered attitude towards HSW and the interview process. G3 was generally very optimistic and positive, characteristic of a newly qualified teacher (NQT) early in her first year. It seems unlikely that these three teachers formed a distinct group and therefore their data must be seen as representative, just as those of the others.

- Some time has passed since the curriculum change was introduced, so teachers have had time to reflect on the requirements and accommodate any necessary changes. This may mean that they have overcome any initial problems or reluctance and have mellowed. It is possible that some of the participants would have been considerably more negative if they had been interviewed a few years earlier.

- Heads of Department with a generally negative attitude towards the policy may have simply and actively ignored the researcher's emails. It is strange, however, that not a single one would bother to respond with a brief explanation that they felt this was not the kind of research to take part in. Some other non-participants did take the time to send a reply to decline, but never because they felt HSW was not worth talking about.

The spectrum of readiness to change is different from other similar classifications as presented in the literature. It allows for the inclusion of a pioneering role, which has not been seen in other frameworks. The "innovator" described by Rogers (2003) comes closest, but there is a big difference between the two frameworks: Rogers' is fully chronological, and an innovator is an innovator by the very nature of being one of the first to embark on a new development (embracing a new technology is the most often quoted context of his framework). The spectrum of readiness to change, however, allows for a practitioner changing their approach over time. A pioneer is most likely always a pioneer, although even a pioneer may become disheartened over time. In addition, the spectrum of readiness to change allows for any one person to exhibit traits of more than one role, related to different aspects of the new development under consideration. None of the other frameworks as described in the literature, such as the Rational Man/Cooperator/Powerless Functionary (Sieber, 1972) and the derived rational adopter/pragmatic skeptic/stone-age obstructionist continuum (Doyle & Ponder, 1977-78) have these features.

9.2.4 Teachers' feelings about the influence of HSW on their practice

Change can be a good thing in itself, to keep things fresh (e.g. Teacher G3, see section 7.2.4). It is not unreasonable, however, for people to request change to happen only if there is evidence that there may be good reasons to change (e.g. Teachers C1 and F3, see sections 7.3.5 and 5.3.5 respectively).

In order to discuss how teachers feel about the changes they feel they have made or had to make, a useful link can be made with the ‘value congruence’ of Harland and Kinder (1997). They claim that, in the realm of continuing professional development (CPD) and specifically that connected to imposed change, changes in classroom practice are much more likely to occur if the teacher’s and CPD provider’s values and beliefs coincide. In the current study, this effect is seen in a number of participants. Teacher C1 is the most obvious example: his department had started to move towards incorporating more skills teaching because they believed that was the right direction. This was borne out by the 2004 curriculum change where skills, among other aspects of HSW, received increased emphasis. Teacher G1, a self-confessed cynic and very different from C1 in his approach, is nevertheless similarly looking for confirmation of his own beliefs in a good education whenever a new curriculum comes out. Both these teachers felt they found what they were looking for in the HSW strand of curriculum.

9.2.5 The influence of HSW on teachers’ classroom practice

Although the perceived need to change because of the increased emphasis on HSW in the NCASC was variable in the participants in this study, they all talked readily about the various aspects of HSW and how they accommodated these into their practice. They reported being under the influence of their own philosophy as well as that of the courses they were teaching. They were influenced by what the examinations required their pupils to know and to be able to do. These factors, and some others, had a direct impact on what teachers felt they needed to do in their teaching. It was not just the teachers who talked more extensively about certain aspects of HSW relative to others; the other practitioners also put varying emphasis on the different aspects, indicative of the courses or projects they were involved with.

The investigative aspect of HSW received the most attention in teaching as well as in interviews, partly influenced by the more stable presence in the NCASC, partly due to more obvious and perhaps more successful examination. Other aspects of HSW received more varied attention but there were plenty of examples in the data. The Skills

Agenda, whether explicitly or implicitly, also had a noticeable impact on the teachers' practice.

It has become clear that HSW, which is broader than NoS or any other element of curriculum which cannot be said to be specifically related to science content knowledge, has been successfully adopted into science teaching and learning. The current study shows that secondary school science teachers cope extremely well with the broader range of requirements. In fact, they applaud it. They feel it clarifies the role of the science teacher and the role of science as a subject as part of a secondary school education. None of the separate aspects of HSW are new to science teaching and learning, but having the whole of HSW together makes it obvious and unequivocal for the wide range of teachers studied, whether they initially were sceptical about some or all of it, or whether they feel they had already been teaching it before it even became an explicit separate part of the curriculum.

In answer to research question 1 (How does HSW influence science teachers' classroom practice?) it can be said HSW has had a varied but generally positive effect. Many teachers now give more considered attention to philosophical aspects such as the importance of evidence and the tentativeness of scientific knowledge, although they also acknowledge it depends on the depth of the assessment how far they take this attention. Some say it is sufficient to treat some of the philosophical and socio-scientific aspects through anecdotes rather than dedicated teaching episodes. This means that, although they might say that there is nothing about HSW they would not do if it was no longer part of the curriculum, there are aspects which perhaps do not receive the attention they should. More effective assessment of these aspects would probably change this partial avoidance.

The response to change itself also plays out variably among teachers, resulting in a spectrum of readiness to change: teachers in this study were pioneering, embracing or following the requirements of the change, with very few and only isolated pockets of reluctance or subversion.

9.3 Further reflections on science education and teaching

9.3.1 Overview – addressing research question 2

Research question 2 asked:

Does the presence of *How Science Works* in the science curricula 11-18 influence science teachers' thinking about secondary school science and how it should be taught?

If so, what is the influence? What are teachers' own views about *How Science Works*? Have teachers' views of science and teaching changed since the introduction of *How Science Works*?

Factors of influence on teachers in their teaching practice can be subdivided, on the basis of a framework developed by Goodson (2003), into *external*, *internal* and *personal* agents. The increased emphasis on HSW in the NCASC can be seen as an *external* agent on a teacher's practice, as it originates outside the school environment. Factors affecting the whole school but instigated from within the school, such as a school's ethos, are classed as *internal* agents. A teacher's professional biography is among the *personal* agents as defined by Goodson. These and other influences are discussed in section 9.3.2.

Goodson's *personal* agents are often related to a teacher's personal beliefs about their job, their subject and their own development, leading to their own views of how science works which are examined briefly in section 9.3.3.

Summarising the findings from chapter 6 in the context of the literature and with additional findings from chapter 8, section 9.3.4 will present answers to research question 2.

9.3.2 The increased emphasis on HSW cannot be seen in isolation

Many factors have influenced teachers' approaches to teaching science during the period since 2006, in addition to the changed curriculum with the increased emphasis on HSW. A useful way of categorising these factors is the framework developed by Goodson (2003), in which the curriculum is one of the *external* influences on a teacher's practice, and other factors can be recognised as *internal* or *personal* influences. Goodson described a similar sentiment to that of Harland and Kinder's value congruence (Harland & Kinder, 1997): the harmonisation of all influences on teachers makes educational change more likely to gather momentum, just like a change in practice is more likely if a teacher's values and beliefs are in congruence with those of the CPD they are undergoing.

Some of the factors which have influenced teachers have such overlap with the effects of HSW in the NCASC that it is difficult to disentangle their influences. Examples of these which were brought forward by teachers are Assessment for Learning (AfL), Assessing Pupils' Progress (APP), and course change. These influences, mainly *external* in nature, will have worked together to strengthen the effect of the curriculum change in which HSW gained prominence. AfL and APP brought techniques and procedures which are eminently suitable for the assessment of HSW. The Skills Agenda also seems to be an influence in this context, although none of the teachers mentioned this explicitly.

In the realm of *internal* influences, the teachers in the current study referred to cross-curricular and inter-departmental effects where whole-school activities such as learning skills sessions and a concerted effort to rely less on teacher talk have had a beneficial impact on pupils' understanding of HSW. Again, the effects of these factors are difficult to distinguish from direct effects of the curriculum change and should be seen as cumulative.

Teachers also brought a whole host of *personal* influences to the table. A major factor in teachers' approach to HSW is whether or not they have been involved with post-graduate research. However, unlike Ryder and Banner's (2013) finding that these teachers were considerably more likely to be specifically concerned with their pupils' future as scientists, these teachers in the current study were merely thankful for their experiences as a foundation for their philosophy of science and the inspiration they could draw from it when teaching. The goal scepticism Ryder and Banner found around the need for future scientists and scientific literacy, also more prevalent in their post-graduate researcher teachers, was again not seen specifically in those teachers in the current study. Goal scepticism was much more related to a mismatch of the different levels of curriculum as Van den Akker (2003) described them and noted by a wider variety of teachers.

And finally, further major *personal* influences teachers described, were maturity and confidence, the latter seen as personal triumph when new approaches were mastered, and the former acknowledged as part of an almost automatic process towards a better understanding of HSW and better teaching of it.

9.3.3 Teachers' views about how science works

Although the current study cannot do justice to the vast amount of research and related literature about science teachers' views of the nature of science, some conclusions can be drawn from the teachers' interviews about their philosophy of science and the related development in their thinking about science teaching. Most of the interviewees had a favourite aspect of HSW or spontaneously spoke more about some aspects of HSW than others. Communication (C) was very rarely mentioned, although a sub-group talked about the terminology connected to investigative science, some more positively than others. Investigative science (I) as a whole, on the other hand, received mention in the majority of cases. History and philosophy of science (H) and socio-scientific aspects (S) were emphasised spontaneously by a few individuals, who were overtly passionate about those aspects and hence positive about the increased emphasis on those in the NCASC. In addition to some or all of these four strands of HSW, almost all interviewees highlighted the need for an emphasis on skills. This often mainly related to practical investigative skills, but turned out to be taken more broadly by a number of interviewees, who described critical thinking skills, debating skills and other communication skills.

The increased emphasis on HSW in the NCASC has clarified some teachers' own views of how science works. As there are also teachers who acknowledged they do not read the NC documents themselves but tend to work from materials which have gone through at least one interpretation already, the clear grouping and overview which the key stage 4 (KS4) NC (DfES & QCA, 2004) provided, may have passed some by. This is a key issue which might influence future curriculum developments.

9.3.4 The influence of HSW on teachers' thinking about science teaching more broadly

The increased emphasis on HSW in the NCASC has certainly had an effect on teachers' thinking about their practice and science teaching more broadly. A major effect is the emphasis on skills. This effect is not just about skills related to practical investigative science, which have received emphasis in the NCASC ever since the inception of the National Curriculum in 1989 (and before). It also refers to a range of skills and aptitudes needed to develop scientific literacy, such as critical thinking and communication skills, ethical awareness, and the ability to apply scientific knowledge to new situations.

In answer to research question 2 (Does the presence of HSW influence teachers' thinking about science teaching more broadly?) it can be said that teachers realise that many factors work together to influence their teaching and their professional thinking, and it is not always possible to pin down how much of a change is due to one specific factor. The HSW strand of the curriculum has made teachers think about their approach to skills teaching and their confidence in using certain teaching approaches which may be required for the successful teaching of HSW.

From the brief probing into teachers' own views of how science works, it seems that many teachers have an incomplete or immature view of the nature of science. This is concordant with the large literature on Nature of Science (NoS). As teachers tend to depend to a large extent on textbooks and schemes of work produced by others, there is hope that the interpretation of HSW in those materials gives pupils a fuller exposure to the whole range of HSW-related aspects than might have happened if all teachers were left to their own devices in this respect. Some teachers freely acknowledged that they may have had gaps in their understanding of some aspects of HSW.

9.4 Evaluating the explicit emphasis on HSW

9.4.1 Overview – addressing research question 3

Research question 3 asked:

Do teachers see the more explicit emphasis on *How Science Works* as a positive development?

If so, why do they think so? If not, what are their reasons?

The teachers and related practitioners were generally positive about the emphasis on HSW in the NCASC. Their main arguments are highlighted in section 9.4.2. Although all were generally positive, it is unlikely that in a population as heterogeneous as in the current study, all participants would agree on everything. Some of the most prominent issues which raised alternative responses are highlighted in section 9.4.4.

Summarising the findings from chapter 7 in the context of the literature and with additional findings from chapter 8, section 9.4.5 will present answers to research question 3.

9.4.2 A generally positive outlook on the emphasis on HSW

Despite the interviewees displaying a range of attitudes from pioneering to subversive to a larger or smaller extent, they were all generally positive towards the presence and prominence of HSW in the NCASC. The main reasons are that, for their own or other teachers' benefit, it highlights the importance of HSW, and clarifies the aspects of HSW for teaching. When these reasons chime with a teacher's own views of how science works and how they would like to teach, this results in a positive attitude towards the change.

In some historical versions of the NCASC certain aspects of HSW, most notably History and Philosphy of Science (HPS), have either been absent or put in a section where it was made clear that it was not going to be part of statutory assessment. In the version under study, however, ignoring one or other aspect of HSW does not match the spirit of the curriculum. It is all given prominent attention in the documents, all under the same heading, so it all requires teachers' and learners' attention. Despite this there may be reasons, such as the absence of effective or challenging exam questions, which appear to allow teachers to ignore parts of it. Other practitioners confirmed that this is possible. Teachers and examiners agreed that there is little value in the rote learning that 'advantages and disadvantages of a certain technology' invariably refer to economical, social and ecological factors which can be rote learnt, as it does not really represent an understanding of HSW. Examiners try hard to develop questions which test understanding rather than rote learning, but until they succeed, teachers will persist with either ignoring teaching such aspects of HSW explicitly, or teaching their pupils to learn answers to such questions by rote.

In the context of Van den Akker's (2003) subdivision of the curriculum (intended, implemented and attained, see section 2.3.2), most of the teachers saw themselves more as implementers and users of the curriculum than producers. Some of the other practitioners expressed more explicit views of what the intended curriculum should be like, and made suggestions about a different grouping of aspects, different emphases and the need to have specific criteria for the different science subjects. Some literature, e.g. Rudolph (2000), suggests that keeping the science subjects more separate, including any discussion of their philosophy and therefore HSW, may also be beneficial for pupils.

9.4.3 Related practitioners' influences on the curriculum

Teachers viewing themselves more as implementers and users of the curriculum rather than producers, is just as Van den Akker found it. While Bernstein's (2003) scheme allows for, or even encourages, teachers' involvement at level 1, it is rare in the teachers in the current study. None of them talked about direct involvement with specifications or textbooks and their developers. Some described encounters with awarding bodies but these were limited to teachers gaining a better understanding of the assessment models and the appropriate teaching of the content, rather than impacting the specification in a direct way. Bernstein's framework does explicitly mention "education authorities, syllabus writers, and education advisors", the first two at the level of recontextualisation (Van den Akker's level 1b) and the latter at the level of reproduction (Van den Akker's

2a and perhaps 2b). Nowhere in Bernstein's framework is there mention of the influence of examiners in this.

In the current study, a sizeable proportion of the teachers are trying to take direction from the interpretation of the curriculum documents by specification and textbook writers, and to align their interpretation with the intentions of examiners. These other practitioners therefore have a considerable influence on the implementation of the curriculum by teachers, including the emphasis teachers place on HSW.

The textbook writers in this study are conscious of their role in interpretation of the curriculum documents into a slightly different form (level 1b). They do not seem quite so aware of the effect their interpretation may have on some teachers, as these may take the textbook's interpretation as full and complete, not giving much thought to the implications of the philosophy behind the textbook's development. On the other hand, some textbook developers' philosophical background is so inherent in the type of textbook they are involved with that the implicitness of the philosophy, and the teachers' whole-hearted embrace of the textbook as a guide, would be just what they would hope to achieve. Their role in teaching teachers some of the aspects of HSW, especially related to the philosophy of science (or the broader NoS), does not seem generally accepted by textbook writers. This could be developed, as teachers seem to acknowledge that at least some of them require development in this area, which textbooks and related resources might be able to provide.

The role of education advisors in this study aligns very well with that suggested in Bernstein's framework, although a considerable amount of their work is in the development of resources which might be said to be more at level 1b than at level 2, for teachers to pick up and use at their own convenience, rather than the advisors being directly involved in the development of lesson materials as would be more appropriate to their level 2 involvement.

The role of examiners is not described at all in the frameworks highlighted in the literature. Their efforts translate into an interpretation of the curriculum documents on the basis of lesson outcomes rather than lesson intentions. This has become extremely important for teachers to engage in, in a culture of school league tables and performance management. That which can be assessed, is taken up into teaching in such a way that assessment becomes part of it and expected to be so, and that which seems desirable and important to be taught, must therefore be part of assessment so that teaching is ensured. Examiners' roles are therefore much broader than just at the level of the attained curriculum (level 3), as their involvement has a direct effect on the implemented curriculum (level 2). Moreover, it is not unusual for the specification to be written in such a way that assessment follows naturally from the specification, so some of their work also has an effect on the curriculum at level 1.

9.4.4 Alternative outlooks on the emphasis on HSW

While the participants in the current study generally had a positive opinion of the emphasis on HSW in the curriculum, some alternative, more negative, responses were seen to some aspects of it.

Firstly, it is very difficult to describe HSW-related curriculum aspects in such a way that it is clear what an understanding of such aspects means (Millar, 2012). Progression, the development of such an understanding over time, was seen as not adequately addressed in the current NCASC both by teachers and other practitioners. Teachers also recognised the near absence of challenging HSW-related aspects and examination questions at A-level. This, and other factors, resulted in a certain measure of goal scepticism about the mismatch between levels of curriculum in some of the teachers, namely Teachers E3, G1 and I3 (see section 6.4.4.). Most notably, Teachers E3 and G1 also displayed the most obvious pockets of subversion (see section 9.2.3).

Secondly, some teachers highlighted the increased emphasis on HSW in the curriculum as a rebranding exercise, which, as some teachers highlighted, may have been a good thing simply to increase teachers' awareness of its importance. The recognition that rebranding might be beneficial has parallels with the recognition that change in itself may be good to keep things fresh (see section 9.2.4). It is unlikely that HSW was simply introduced as a rebranding phrase, but it is easy to use and covers the contents, which is what teachers have picked up on. That teachers even mentioned it in terms of rebranding in the current study means that it seems to have worked, intentionally or not.

And thirdly, a number of teachers pleaded for the government to leave the curriculum alone for a while, and to only change it on the basis of good evidence. They felt that curriculum change happened too often, and there will not have been time to collect enough evidence to suggest that the previous version had worked or not.

9.4.5 Teachers' views of the more explicit emphasis on HSW

In answer to research question 3 (Do teachers see the more explicit emphasis on HSW as a positive development?) it can be said that in general the teachers in the current study all saw the more explicit emphasis on HSW as a positive development. Their main argument is that it highlights the importance of HSW, and clarifies the aspects for teaching. Although not all of them felt that the curriculum needed to spell out HSW in this much detail for themselves so much as perhaps for other teachers, they acknowledged that is a useful aide-mémoire. They also highlighted that where examination questions and assessment methods were appropriate, it gave their pupils opportunity to show their understanding of how science works.

They were not quite so unanimous about issues of progression, discrimination and successful effective assessment. In this, their arguments were confirmed by the related practitioners. The problems related to these issues are becoming better known in the literature, whereas an understanding of possible solutions is not quite so promising yet but will hopefully follow.

9.5 A critique of the study

9.5.1 Overview

In retrospect, some aspects of the overall research strategy of the study worked well whilst others could have been improved. Strengths and weaknesses of the research strategy will be explored in the following sections.

The instruments, namely the interview schedules (see appendix B), performed well, after the pre-pilot and pilot stages. Although there was no discernible overlap between the interview questions, interviewees' responses to different questions allowed for some validation of their answers through checking for consistency.

9.5.2 Sampling

Although randomised sampling is the gold standard for most research, it became clear early on in the recruitment process that a different approach would need to be employed to obtain a heterogeneous sample which might be seen as reasonably representative of the population of secondary school science teachers in the UK, as the acceptance rate of teachers chosen at random would probably have been very low. The goal for the interview sample was to achieve an absence of obvious bias. Getting agreement to be interviewed and travel to the interview location were also important practical considerations. In order to obtain a sample of sufficient size, recruitment focussed on those who could be reached reasonably easily. Since none of the participants had taken part in similar research before, nor been involved in discussions about the topic under study with the researcher, there was no outcome-related bias in the sampling. As the resulting sample was indeed heterogeneous on a large number of criteria (see chapter 3) the mainly purposive sampling was successful in this respect.

If there are science teachers who are truly reluctant or even subversive towards the presence/emphasis of HSW in the curriculum, they were not found. As there seems to be an overall positive attitude towards HSW, however, there are no guarantees that ‘reluctant’ participants would have been found within a time frame reasonable for a study such as this. Moreover, if there truly are very few reluctant or subversive teachers in the population, a representative sample should also contain very few, if any. Looking at the interviewees in the order they were interviewed chronologically, namely C1, C2, H1, J1, J2, D1, D2, F1, F2, F3, A1, C3, A2, I1, I2, I3, K1, B1, G1, G2, G3, E1, E2, E3, D3, no significantly new ideas were advanced after Teacher G2 and no significantly new positions were occupied regarding the chart in Figure 9.1. Although the final five teachers expressed their views in ways which have proved useful in developing the arguments in chapters 4 to 7, these merely confirmed or strengthened the points made by teachers earlier on. It can therefore be said that data saturation was reached.

For the sample of related practitioners convenience sampling was employed, with an element of snowballing. The overall numbers of textbook developers, examiners and consultants interviewed were mainly limited by time constraints for the data collection period. On the other hand, these other interviews were never meant to overshadow the interviews with teachers, as teachers were the main subjects of the current study. The group of six textbook developers is heterogeneous if TD4, TD5 and TD6 are considered as one type and TD1, TD2 and TD3 each represent different types, based on variety of experience and commitment to context-based or concept-based learning. TD1 has been involved with numerous courses, both context- and concept-based, but has a slight preference for concept-based work. TD2 has not committed to any course in particular or either context- or concept-based work. TD3 has been involved with one particular exam board and is committed to a concept-based framework. TD4, TD5 and TD6 are textbook developers for context-based A-level courses.

The three consultants have a lot of similarities in their approaches and philosophies, and may or may not be representative of their population. Their population is, admittedly, rather small and shrinking, so it was already difficult to reach any of them. The three in this study certainly all performed very similar roles, each in their own communities.

The two examiners cannot be said to be representative of their whole community. They operate at two different key stages, and their subject background is different, but they are both involved with context-based courses which may mean their views of HSW and the way it is and should be taught, and the way it is and should be examined, are biased. Given more time, more examiners would have been approached and an effort would have been made to interview other ‘types’ of examiners.

9.5.3 Role of interviews with teachers

When looking to answer questions of opinion as well as matters of fact, semi-structured interviews are the most fruitful method to collect data, as they allow for a discussion of not only *what* people do and think, but also *why*. It makes it possible to probe further to get examples of actual practice, and to get a good understanding of each individual teacher’s opinions and views.

9.5.4 Role of observation

The observations of some teachers’ lessons were intended to gently encourage forthrightness in the interviews, rather than to provide additional data for validation of interview answers. As not all teachers were observed, the data collected during observations cannot be used to corroborate interview statements, but they do allow for a certain amount of strengthening of arguments. Both in the pilot and the main study the practice as reported by the teacher was actually observed in the lessons in most cases, and observed practice never clashed with what teachers reported they do and what they consider important. One observed lesson can scarcely be seen to exemplify a teachers' full range of practice. The eleven observed lessons, however, go some way to indicating that a good range of HSW aspects are dealt with in lessons up and down the country.

9.5.5 Role of interviews with related practitioners

Teachers brought forward issues, such as the lack of examination questions which effectively discriminate between pupils of different ability or the extent to which aspects of HSW were integrated with other aspects of science in textbooks, which could be further informed by interviewing practitioners who were experts about such issues.

Some of the related practitioners were interviewed by telephone rather than face-to-face. Some time was taken at every interview to establish a relationship with the interviewee before the formal interview would start and the audio-recording was switched on. The telephone interviewees seemed comfortable with being interviewed that way – perhaps they are quite used to discussing work-related matters on the telephone. The quality of the responses did not suffer compared to those who could be interviewed face-to-face.

In order to protect the confidentiality of both teachers and consultants, links between teachers at different schools and between teachers and consultants, although they do exist, were not referred to in detail in the reporting. Similar considerations apply to the examiners and textbook developers.

9.5.6 Data validation

Triangulation in the strictest sense, looking at the same problem in three distinctively different ways, is not possible in this case. In practice, however, it still pays to use a variety of methods to check the data in order to feel more confident that it is accurate and reliable is. Had observation been feasible with all the teachers, this would have been a good second method of looking for evidence of teachers' practice. Interview statements from related practitioners allow a strengthening of arguments where the issues under discussion also apply to those related practitioners by virtue of their expertise. A certain amount of informant triangulation is then possible, but only for those specific issues. No pair of the three methods employed, however, covers the same data convincingly enough to consider triangulation as a method for validation.

The data coding and interpretation process requires a different protocol for validation. One route which is advocated is to make repeated tours through the data, with periods of reflection in between (Hutchinson, 1988). If coding activity of the same segment of data results in similar codes each time, intra-coder reliability is achieved. The data were approached with a different emphasis a few times, and ultimately a stable coding scheme was achieved (see chapter 3). In order to apply some measure of cross-validation, it is advised that some of the data is coded by another researcher (or researchers) to check inter-coder reliability, if it is practicable to do so (Vulliamy & Webb, 1992). In the current research, two student colleagues were willing to do this. Unfortunately neither was a native speaker of English and it became prohibitively time-consuming to explain the coding scheme, so the attempts were abandoned. It is difficult to find and persuade somebody with enough background knowledge to perform this task, but more effort might have paid off.

9.6 Implications of the research

9.6.1 Overview

The current study has implications for a number of people: teachers, policy makers, examiners, textbook developers and researchers. These will be discussed in turn below. It must, however, be borne in mind that suggestions for practical implications are more speculative than the research findings themselves.

9.6.2 Implications for teachers

Most of the teachers in the study were fairly confident they were aware what the increased emphasis on HSW required of them. It is believable that the same applies to the larger secondary science teaching population. It became obvious, in some cases, that some of the participants were not quite as familiar with all the requirements as they might have liked. Some acknowledged they needed some targeted CPD, specifically for one or other aspect of HSW, most often related to philosophy. This chimes with research findings of other studies which have suggested that teachers' knowledge of the NoS is often limited (see chapter 2). It is conceivable that CPD would benefit at least a fraction of the science teaching population in general.

A number of science teachers might also benefit from taking the opportunity, or even being given the obligation, to read original curriculum documents and act on those when planning lessons and schemes of work. That way, they would be able to form their own opinion of how the curriculum should be interpreted and what the intended curriculum is, rather than depend on a first layer of interpretation by others such as textbook developers.

9.6.3 Implications for policy makers

Since not all teachers read the original curriculum documents, this may be the first issue for policy makers to consider. The HSW statements can be and are interpreted in a variety of ways, as highlighted most emphatically by examiner EM2 (see section 8.3.1.). In order for the policy to be understood as intended, and implemented effectively and consistently, unambiguous statements are required. This may mean a more comprehensive description is needed for some of the statements. In addition, it might be even better if teachers are provided with a sample set of questions which could be used in assessment.

As very few teachers will have acquired a formal understanding of all aspects of HSW during their undergraduate degrees or at any other time during their formative years, there are likely to be gaps which a comprehensive programme of CPD might fill. Aspects of philosophy are most probably the areas which need most development. In recent research, trainee teachers showed apathy or a reluctance to acknowledge they needed assistance in their ability to teach about HSW (Lock, Salt, & Soares, 2011), so a policy may be needed to address these problems. 'Perspectives on Science' (University of York Science Education Group, 2007) and its related resources might be usable as a basis for professional development for teachers. It is geared towards the teaching of history, philosophy and ethics of science to A-level pupils, contains suggestions for background reading for teachers, and thus probably provides the majority of teachers with all they will need for their secondary school science teaching. Another valuable resource may be the HSW road map (see section 8.4.1).

More effort needs to be put into the development of HSW statements which show a progression over the key stages (see section 8.4.2 where consultants and Teacher F3 argue for this). This is a difficult task. Progression is most commonly linked to scientific content knowledge while it is much more difficult to describe a progressive development of understanding of how science works without relating it to content (Millar, 2012).

Despite some teachers' struggle with some of the aspects of the philosophy of science, it seems the clarity and breadth of HSW in the curriculum is a promising way forward in encouraging teachers to engage with all aspects of HSW.

9.6.4 Implications for examiners

Data handling questions are much appreciated by teachers. They are seen to assess skills and understanding in an appropriate, stimulating and successful way. If other aspects of HSW were equally effectively assessed, this could have a significant bearing on teachers' practices. Until such time as all aspects of HSW play a significant role in examinations, teachers will persist in interpreting curricula in a way which suits them, and with an emphasis on those parts of assessment which they feel requires a concerted effort in their teaching. Examiners are already fully aware of the influence assessment has on teaching, and should extend their efforts to develop assessment methods and examination questions which do justice to all the requirements of HSW.

9.6.5 Implications for textbook developers

Some of the textbook developers had not given consideration to the notion that teachers might not only rely on the textbook for an interpretation of the curriculum, but also for support of their own development of certain aspects of it. Especially in the realm of philosophy of science, this puts quite a burden of responsibility on the textbook and therefore on the textbook developer. If some of the developers' reflections are anything to go by, this responsibility is taken on variably, and may require some more concerted effort.

9.6.6 Implications for researchers

The spectrum of readiness to change provides a useful framework to study the impact of policy change on teachers. It is seemingly related to the Wellcome Trust framework for teachers' appraisal of CPD, which signalled a population of believers, agnostics, seekers and sceptics (in diminishing quantities, respectively) (Finegold, 2006). A crucial difference, however, it that teachers usually have some control over their participation in CPD which is not the case for policy change such as the one under study. Its similarity with other frameworks in the literature, such as Sieber's, and Doyle and Ponder's, breaks down on other aspects, most notably the presence of a role of 'pioneer' in the spectrum of readiness to change. It must therefore be considered as a new framework in the field of educational change.

Goodson's framework has proved very useful in the analysis of the data from the current study, regarding the context of influences around the specific 'change' of the increased emphasis on HSW in the NCASC. Smaller and larger changes will have a variety of impacts, but these changes and their surrounding influences can always be related to Goodson's framework.

As mentioned in the context of implications for policy makers, the clarity and breadth of HSW in the curriculum has seen a more extensive engagement of teachers with the full range of aspects of NoS, socio-scientific issues, science inquiry and scientific communication than has been seen before. It warrants more, and perhaps international, research to discover the full extent of the benefit of expressing these aspects of science education in the way that has been done for HSW.

A number of other ideas have come to the surface from the current research:

- With current curriculum developments in mind, teachers' attitude to HSW-related aspects can be studied further, against the backdrop of a new curriculum which seems more geared up for teaching and learning of scientific content knowledge rather than HSW.

- There might be a way to develop a survey on the basis of the current study, to probe a larger sample for sentiments of reluctance and/or subversion. This would have resulted in a better indication of data saturation.

- It might have been useful to interview technicians. Those with a number of years of experience, and an overview of the teaching year, talk readily about activities which require their concerted efforts at certain times of the year, when teachers all request a large amount of pondweed, for example. If such an activity suddenly no longer takes place, experienced technicians would notice. They may not make the link with a changed curriculum, but such information might add valuable data.

- It would be useful to make the link with tertiary education: what are the qualities students bring to their undergraduate studies if they have received a secondary education in which HSW has played a significant role, and do university staff recognise and/or appreciate the efforts around HSW?

- Short of recommending the use of ‘Perspectives on Science’ and its related resources for professional development for teachers outright, its effect could be investigated first on a sample of teachers.

9.7 Concluding comments

A wider range of teachers participated in the current study than have ever been studied before in the context of HSW (see Ryder & Banner, 2013; Toplis et al., 2010). It was not the aim to attribute any particular attitudes or practices to any sub-group of teachers, and there do not seem to be any obvious differences with school type, gender, level of experience or any of the other criteria with which the teachers might have been categorised in advance. Rather, the aim was to get an overview of the effect of the curriculum policy change on the ground, from a variety of teachers from a wide range of the secondary school science teaching community. In this, the study was successful and an interesting variety of responses was seen.

The policy was effectively anticipated by pioneering teachers, in retrospect eagerly awaited by some of the keener embracing participants, and the remainder were eager to perform their duty as professionals and followed the policy change within the required timescale. More negative pockets of sentiments, namely some isolated instances of subversion in the otherwise generally positive participants, did not allow for an allocation of even a single individual in the current sample to the most negative parts of the spectrum. The *spectrum of readiness to change* can probably usefully be applied in the preparation and study of other policy changes in education.

Similarly to there not being a consensus response to the policy change, there is no single view of how science works, and according to the teachers in this study there is no single way to teach the 'other' aspects of science which do not belong with any one type of science in particular. Teachers find their own way, within the boundaries of their professionalism, less or more creative, less or more appropriate to the current philosophy of science, and less or more appropriate and effective regarding their pupils' levels of attainment. There is a considerable emphasis on teaching to the exam, or at the very least making sure that the teaching matches the emphases as present in the assessment, and therefore playing down aspects which are not successfully or even obviously examined.

Examiners acknowledged that teachers have rightly and correctly picked up on weaknesses in the products of their professional efforts. Exams do not cover all aspects of HSW equally and effectively, and more concerted efforts are required, and under way, to address the issues.

Textbook developers acknowledged that they are committed to make explicit the philosophy of the course they are involved with through the textbooks. On the other hand, they did not readily take responsibility for the enhancement of teachers' understanding of the philosophy of science through their textbooks or accompanying teacher materials, which is something which some teachers might have benefited from. Although textbooks provide teachers with a guide for the teaching of HSW to their pupils, for their own development teachers have to depend on support from colleagues, consultants, and courses from Science Learning Centres and other providers.

And finally, teachers do not seem particularly interested or confident in actively influencing the intended curriculum, other than that they wish the curriculum would be left alone for long enough for evidence to be collected and analysed as to whether the curriculum is effective or not, and how teachers have implemented it. Teachers' passiveness in this area is borne out in the literature – relatively few practising teachers publish in their own professional journals such as *School Science Review* or *Education in Science*. It is also reflected in Van den Akker's (2003) curriculum framework which places teachers' roles firmly at level 2. And although Bernstein (2003) suggests teachers could and should be involved with curriculum development at level 1, it is not seen by the teachers in the current study as something they would engage in.

The current project set out to study a more varied population of secondary school science teachers than had been studied before, in relation to their classroom practice in response to a curriculum change in which HSW received a much increased emphasis. In addition, the teachers' thinking about their practice and the curriculum change itself was examined, and the resulting conclusions further informed by the reflections of textbook developers, examiners and science education consultants regarding aspects in which these related practitioners have appropriate expertise. The majority of the teachers acknowledged they had made changes in response to the increased emphasis on HSW, expanding their repertoire of teaching methods and activities, and putting more emphasis on certain aspects. HPS and socio-scientific aspects received the most additional attention, as did skills not related to the practical investigative aspect of science. It has to be acknowledged in turn that the sentiments of all aspects of HSW had been present in previous versions of the NCASC, although never as comprehensively set out as in the version under study, and never before had all of it been included for statutory assessment. A number of teachers and related practitioners identified this continuity, and used it as justification for not changing all of their practice radically. In addition, teachers adjusted their practice to the requirements of assessment as they perceive them. In the process of evaluating teachers' responses, the *spectrum of readiness to change* was developed, which merits consideration in other studies of people's responses to change.

Appendix A. *How Science Works* in KS3, KS4 and KS5, and APP at KS3

At KS4 for 2004 (DfES & QCA, 2004) – for first teaching in 2006 – the curriculum was at its most compact, and easy to use for reference with interviewees. *How Science Works* occupied one page of A4, while the rest of the curriculum, the canonical science knowledge, occupied another. See below.

The KS3 curriculum for 2007 (QCA, 2007a) – for first teaching in 2008 – did not have a separate section under a HSW heading. Instead, it had two sections which together might be considered to comprise HSW, namely ‘Key concepts’ and ‘Key processes’. See below. The five Assessment Foci for APP (Assessing Pupils’ Progress) (collated from: DfE, 2011d) are also included below.

The A-level Subject Criteria for Science (QCA, 2006) – for first teaching in 2008 – dedicated one section to HSW, which covered the same ground as HSW at KS4, but in 12 statements rather than 14. The twelve subject criteria regarding HSW for A-level science are reproduced here (QCA, 2006, p. 4).

The skills, knowledge and understanding of How science works must include the requirements set out below, and must be integrated into the mandatory content indicated in the relevant appendix and any content added by the awarding body.

1. Use theories, models and ideas to develop and modify scientific explanations.
2. Use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas.
3. Use appropriate methodology, including ICT, to answer scientific questions and solve scientific problems.
4. Carry out experimental and investigative activities, including appropriate risk management, in a range of contexts.
5. Analyse and interpret data to provide evidence, recognising correlations and causal relationships.
6. Evaluate methodology, evidence and data, and resolve conflicting evidence.

7. Appreciate the tentative nature of scientific knowledge.
8. Communicate information and ideas in appropriate ways using appropriate terminology.
9. Consider applications and implications of science and appreciate their associated benefits and risks.
10. Consider ethical issues in the treatment of humans, other organisms and the environment.
11. Appreciate the role of the scientific community in validating new knowledge and ensuring integrity.
12. Appreciate the ways in which society uses science to inform decision making.

The full HSW section of the KS4 curriculum is reproduced here (DfES & QCA, 2004, p. 37). The subsections are represented by one-letter abbreviations throughout this thesis, namely H (history and philosophy of science), I (investigation and inquiry), C (communication) and S (socio-scientific aspects).

How science works

Data, evidence, theories and explanations

Pupils should be taught:

a. how scientific data can be collected and analysed
b. how interpretation of data, using creative thought, provides evidence to test ideas and develop theories
c. how explanations of many phenomena can be developed using scientific theories, models and ideas
d. that there are some questions that science cannot currently answer, and some that science cannot address.

Practical and enquiry skills

Pupils should be taught to:

a. plan to test a scientific idea, answer a scientific question, or solve a scientific problem
b. collect data from primary or secondary sources, including using ICT sources and tools
c. work accurately and safely, individually and with others, when collecting first-hand data
d. evaluate methods of collection of data and consider their validity and reliability as evidence.

Communication skills

Pupils should be taught to:

a. recall, analyse, interpret, apply and question scientific information or ideas
b. use both qualitative and quantitative approaches
c. present information, develop an argument and draw a conclusion, using scientific, technical and mathematical language, conventions and symbols and ICT tools.

Applications and implications of science

Pupils should be taught:

a. about the use of contemporary scientific and technological developments and their benefits, drawbacks and risks
b. to consider how and why decisions about science and technology are made, including those that raise ethical issues, and about the social, economic and environmental effects of such decisions
c. how uncertainties in scientific knowledge and scientific ideas change over time and about the role of the scientific community in validating these changes.

The 'key concepts' and 'key processes' sections of the KS3 curriculum are reproduced here (QCA, 2007a, pp. 208-209).

Key concepts

There are a number of key concepts that underpin the study of science and how science works. Pupils need to understand these concepts in order to deepen and broaden their knowledge, skills and understanding.

Scientific thinking

a. Using scientific ideas and models to explain phenomena and developing them creatively to generate and test theories.
b. Critically analysing and evaluating evidence from observations and experiments.

Applications and implications of science

a. Exploring how the creative application of scientific ideas can bring about technological developments and consequent changes in the way people think and behave.
b. Examining the ethical and moral implications of using and applying science.

Cultural understanding

a. Recognising that modern science has its roots in many different societies and cultures, and draws on a variety of valid approaches to scientific practice.

Collaboration

a. Sharing developments and common understanding across disciplines and boundaries.

Key processes

These are the essential skills and processes in science that pupils need to learn to make progress.

Practical and enquiry skills

Pupils should be able to:

a. use a range of scientific methods and techniques to develop and test ideas and explanations
b. assess risk and work safely in the laboratory, field and workplace
c. plan and carry out practical and investigative activities, both individually and in groups.

Critical understanding of evidence

Pupils should be able to:

a. obtain, record and analyse data from a wide range of primary and secondary sources, including ICT sources, and use their findings to provide evidence for scientific explanations
b. evaluate scientific evidence and working methods.

Communication

Pupils should be able to:

a. use appropriate methods, including ICT, to communicate scientific information and contribute to presentations and discussions about scientific issues.

APP – Assessing Pupils' Progress

Assessment Focus 1: Thinking scientifically

1. Using models for and in explanations
2. Weighing up evidence to construct arguments and explanations
3. The process of developing ideas including the role of the scientific community
4. Provisional nature of scientific evidence

Assessment Focus 2: Understanding the applications and implications of science

1. Effect of societal norms (political, social, cultural, economic) on science
2. Creative use of scientific ideas to bring about technological developments
3. Implications, benefits and drawbacks of scientific and technological development of society and the environment
4. How science relates to jobs and roles

Assessment Focus 3: Communicating and collaborating in science

1. Using appropriate presentation skills to enhance communication of scientific findings and arguments
2. Explaining ideas and evidence using appropriate conventions, terminology and symbols
3. Presenting a range of views judging any possible misrepresentation
4. Scientists communicating worldwide using conventions

Assessment Focus 4: Using investigative approaches

1. To plan appropriate scientific investigations effectively
2. To identify and manipulate variables within the context of an investigation
3. To support the gathering of evidence through collection of precise and reliable data
4. To be aware of the risks associated with the investigative process

Assessment Focus 5: Working critically with evidence

1. Evaluation of the planning and implementation of scientific investigations
2. Consideration of errors and anomalies
3. Processing and analysing data to support the evaluation process and draw conclusions
4. Explanation and evaluation of evidence to support the scientific process

Appendix B. Interview schedules and consent forms

For the semi-structured interviews, interview schedules were developed. These are reproduced here. All interviewees filled in a consent form, either on paper or electronically; the pro-formas are reproduced here.

Interview schedule – teachers

Introductory interview questions

Administrative questions about length of teaching experience, subject specialism, key stages taught, specifications and textbooks used – these were not audio-recorded.

Audio-recorded interview

1. Can you tell me about when or how you became familiar with the term *How Science Works*?
2. What do you think the main elements of *How Science Works* are?
    a. Has your interpretation of *How Science Works* changed since you first heard the term?
3. What kinds of things do you do to teach *How Science Works*?
    a. Does the new emphasis on *How Science Works* mean you have done things differently *since* or *because of* it?
    b. Is there anything you do in your teaching that you might not do if *How Science Works* was not in the curriculum?
    c. Are there some lessons where your teaching objectives are all about *How Science Works*?
    d. What proportion of lesson time overall would you say you dedicate to *How Science Works*?
    e. Do you spend more lesson time on *How Science Works* in some key stages compared to others?
4. Do you use any different teaching approaches for *How Science Works* compared to your other teaching?

   a. Has the increased emphasis on *How Science Works* changed your teaching in any other way?

5. When you teach a particular aspect of *How Science Works*, how do you judge what your pupils have learnt?

   a. Is the way you teach *How Science Works* influenced by how it is assessed?

6. What is your own view of how science really works?

   a. Where does this view come from?

   b. How well does the curriculum interpretation of *How Science Works* match your view?

7. Do you think the emphasis on *How Science Works* in the curriculum benefits your pupils?

   a. Do you think an understanding of *How Science Works* is improving pupils' learning of science?

Interview schedule – textbook developers

Introductory interview questions

Administrative questions about textbooks involved with (past and present, specifically since HSW, and which key stages they are for), degree background, teaching experience, and anything else that may be important to the interview or the data obtained – these were not audio-recorded.

Audio-recorded interview

1. Has the way you write textbook material changed as a result of the greater emphasis as now is on HSW?

   a. If yes, can you give examples? If no, why?

2. Is HSW implemented as a separate unit in the textbook(s) you have been involved with? Fully integrated? Mixture of the two?

   a. Do you think the NC requires you to do that?

   b. What made you decide to implement HSW this way?

   c. How are the links made with the scientific content?

3. How much teaching time would you expect a teacher to spend on HSW?

   a. Are there any official requirements to do this?

4. How much of the textbook relates to HSW?

   a. How does the textbook suggest teaching time might be allocated?

5. Is the treatment of HSW in the textbook related to assessment?

   a. What is the influence of assessment on the textbook?

6. Do you expect teachers to employ specific teaching methods/pedagogies in order to address HSW?

7. What to you are main elements of HSW?

   a. Has your interpretation of HSW changed since you first heard the term? If so, how?

8. With respect to HSW, what have you included in the textbook(s) you have been involved with?

9. What is your own view of the prominence of HSW in the NC?

   a. How is this related to your own view of how science really works?

   b. What do you think about the fit between HSW in the KS3 and KS4 NC and the A-level subject criteria, and what can be expected of pupils at each of those key stages?

   c. What fits? What doesn't?

10. How do you see the role of your textbook in the development of teachers' views of HSW?

Interview schedule – examiners

Introductory interview questions

Administrative questions about association(s) with exam board(s)/examination(s) (and which key stages they are for), degree background, teaching experience, and anything else that may be important to the interview or the data obtained – these were not audio-recorded.

Audio-recorded interview

1. How do you think HSW should be assessed?
2. Do you think the way it is currently assessed is satisfactory?
    a. If no, where and how would you like to see improvement?
    b. If yes, can you comment on
        i. perceived lack of challenge for top students at GCSE;
        ii. perceived lack of discrimination between levels at top end;
        iii. perceived lack of HSW in A-level exams (esp. written)
3. How much teaching time would you expect a teacher to spend on HSW?
    a. What are your reasons for this answer?
4. What is your own view of the prominence of HSW in the NC?
    a. How is this related to your own view of how science really works?
    b. What fits? What doesn't?
    c. Can you give examples?
5. How do you view the role of assessment in the success of HSW (and/or its precursors) as a National Curriculum (A-level subject criteria) entity?

Interview schedule – science education consultants

Introductory interview questions

Administrative questions about degree background, teaching experience, and anything else that may be important to the interview or the data obtained – these were not audio-recorded.

Audio-recorded interview

1. Can you remember what you thought when HSW appeared in the curriculum documents in 2004?
2. What do you think the main elements of *How Science Works* are?
    a. Has your interpretation of *How Science Works* changed since you first heard the term?
3. What do you do to help teachers get to grips with the requirements of HSW?
    a. Can you give examples?
4. How much teaching time would you expect a teacher to spend on HSW?
    a. What are your reasons for this answer?
5. What is your own view of the prominence of HSW in the NC?
    a. How is this related to your own view of how science really works?
    b. What fits? What doesn't?
    c. Can you give examples?
6. How do you view your role in how HSW is implemented in schools?
    a. What do you consider to be 'good practice' with respect to HSW teaching?

Consent form – teachers

Informed Consent Form
Title: The impact on teachers' thinking and on classroom practices of the introduction of *How Science Works* into science curricula 11-18

I understand that I am being invited to participate in a research study conducted by Maria Turkenburg (the researcher).

I understand that the purpose of this research study is to explore the impact on teachers' practices of the increased emphasis on *How Science Works* in science curricula 11-18 from 2006.

I understand that I will be providing information through being observed in one lesson, and an interview in which I will be asked about the implementation of *How Science Works* in my department. I realise that this interview may take up to an hour.

I understand that I may decline to answer any questions and that I may withdraw my agreement to participate at any time during the interview or for up to 7 days afterwards. Within that time, I know that I may indicate whether or not the data collected up to that point can be used in the study, and that any information I do not want used will be destroyed immediately.

I understand that the interview will be audio recorded, and this recording may later be transcribed. I understand that these data will be handled and stored in a manner which ensures that only the researcher can identify me as their source. I understand that I am being offered confidentiality in any written report or oral presentation which draws upon data from this research study, and that none of my comments, opinions, or responses will be attributed to me. I understand that my school will not be identifiable in any written report.

I understand that this research study has been reviewed and received ethical approval following the procedures of the Department of Education.

I agree to take part in the research study as outlined above.

Name of participant: ___________________________________

Signature of participant: ____

Date: ___________________

Consent form – textbook developers

Informed Consent Form
Title: The impact on teachers' thinking and on classroom practices of the introduction of *How Science Works* into science curricula 11-18

I understand that I am being invited to participate in a research study conducted by Maria Turkenburg (the researcher).

I understand that the purpose of this research study is to explore the impact on teachers' practices of the increased emphasis on *How Science Works* in science curricula 11-18 from 2006.

I understand that I will be providing information through an interview in which I will be asked about the implementation of *How Science Works* in the textbooks for which I am/was involved in the development. I realise that this interview may take around half an hour.

I understand that I may decline to answer any questions and that I may withdraw my agreement to participate at any time during the interview or for up to 7 days afterwards. Within that time, I know that I may indicate whether or not the data collected up to that point can be used in the study, and that any information I do not want used will be destroyed immediately.

I understand that the interview will be audio recorded, and this recording may later be transcribed. I understand that these data will be handled and stored in a manner which ensures that only the researcher can identify me as their source. I understand that I am being offered confidentiality in any written report or oral presentation which draws upon data from this research study, and that none of my comments, opinions, or responses will be attributed to me.

I understand that this research study has been reviewed and received ethical approval following the procedures of the Department of Education.

I agree to take part in the research study as outlined above.

Name of participant: ___________________________________

Signature of participant: ____

Date: ___________________

Consent form – examiners

Informed Consent Form
Title: The impact on teachers' thinking and on classroom practices of the introduction of *How Science Works* into science curricula 11-18

I understand that I am being invited to participate in a research study conducted by Maria Turkenburg (the researcher).

I understand that the purpose of this research study is to explore the impact on teachers' practices of the increased emphasis on *How Science Works* in science curricula 11-18 from 2006.

I understand that I will be providing information through an interview in which I will be asked about the implementation of *How Science Works* in the examinations for which I am (partially) responsible. I realise that this interview may take around half an hour.

I understand that I may decline to answer any questions and that I may withdraw my agreement to participate at any time during the interview or for up to 7 days afterwards. Within that time, I know that I may indicate whether or not the data collected up to that point can be used in the study, and that any information I do not want used will be destroyed immediately.

I understand that the interview will be audio recorded, and this recording may later be transcribed. I understand that these data will be handled and stored in a manner which ensures that only the researcher can identify me as their source. I understand that I am being offered confidentiality in any written report or oral presentation which draws upon data from this research study, and that none of my comments, opinions, or responses will be attributed to me.

I understand that this research study has been reviewed and received ethical approval following the procedures of the Department of Education.

I agree to take part in the research study as outlined above.

Name of participant: ________________________________

Signature of participant: ______________________________________

Date: _________________

Consent form – science education consultants

Informed Consent Form
Title: The impact on teachers' thinking and on classroom practices of the introduction of *How Science Works* into science curricula 11-18

I understand that I am being invited to participate in a research study conducted by Maria Turkenburg (the researcher).

I understand that the purpose of this research study is to explore the impact on teachers' practices of the increased emphasis on *How Science Works* in science curricula 11-18 from 2006.

I understand that I will be providing information through an interview in which I will be asked about the implementation of *How Science Works* by the teachers in my area and my role in facilitating this implementation. I realise that this interview may take around half an hour.

I understand that I may decline to answer any questions and that I may withdraw my agreement to participate at any time during the interview or for up to 7 days afterwards. Within that time, I know that I may indicate whether or not the data collected up to that point can be used in the study, and that any information I do not want used will be destroyed immediately.

I understand that the interview will be audio recorded, and this recording may later be transcribed. I understand that these data will be handled and stored in a manner which ensures that only the researcher can identify me as their source. I understand that I am being offered confidentiality in any written report or oral presentation which draws upon data from this research study, and that none of my comments, opinions, or responses will be attributed to me.

I understand that this research study has been reviewed and received ethical approval following the procedures of the Department of Education.

I agree to take part in the research study as outlined above.

Name of participant: ___________________________________

Signature of participant: ____

Date: ___________________

Appendix C. Initial contact email to subject leaders of science

The text of the first email message to prospective teacher participants is reproduced here.

Dear Subject Leader for Science,

I am writing to ask for your assistance with a research study I am conducting. The purpose of the study is to investigate how teachers have responded to the increased emphasis on *How Science Works* in the National Curriculum and A-level Subject Criteria, and their views on this.

I am a PhD student in Science Education at the University of York. My project is funded by a studentship from the White Rose University Consortium (which incorporates the Universities of Leeds, Sheffield and York). The project is supervised by Professor Robin Millar.

For this research, I would ideally like to observe lessons which include some aspect of *How Science Works*, but the most important aspect of my study is to interview the teacher involved. For this to give a more representative picture, I need to select these teachers and schools randomly. I am contacting you because your school was selected as one of a random sample of secondary schools in Yorkshire and Humberside. If you agree to take part in this study, I would like you to select three members of staff in your department, one from each subject discipline and with a range of length of teaching experience, and ask those persons if they would be willing to be observed and interviewed.

If you agree, as I very much hope you will, please reply briefly to me by email, phone, fax or letter to the address below. I will then contact you again to arrange a suitable date for the observation visits and interviews. I will also send fuller details of the interview questions.

The *How Science Works* strand of the science curriculum is likely to come under scrutiny in the current review of the national curriculum and of examinations at GCSE and A-level. Therefore evidence of its contemporary interpretation and impact is timely. The study also hopes to contribute more generally to our understanding of curriculum change. In return for your contribution to the study, I will be happy to inform you in due course of the main outcomes and will send copies of any papers or presentations on the work.

I very much hope you will agree to participate in this study and look forward to hearing from you soon.

Yours sincerely,

Maria Turkenburg
Science Education
Alcuin D107
University of York
Heslington
York, YO10 5DD
Tel. 01904 322585
Fax 01904 323444
Email mgwt1@york.ac.uk

Appendix D. Observed lessons

Observations were performed of as many teachers as were amenable, and whenever a teacher's timetable and lesson planning would allow it, in combination with interview afterwards, on the same day (unless stated otherwise). For each teacher, the following information is given in bullet points:

- Whether they started teaching before or after 2006, and, if they started teaching before 2006, their change-response-group and their position on the spectrum of readiness to change is indicated (see chapter 4);
- Year group of pupils taught, number of pupils in the class, and indication of ability;
- Remark if observation-interview procedure as described was not strictly followed

Then, for each teacher, follows a table including the lesson topic (and subject), a description of the HSW-related activity as observed, and the HSW statements as they were addressed in each lesson (related to the KS4 National Curriculum (DfES & QCA, 2004), in order to get an overview of the full range of HSW teaching observed).

Teacher B1, chemistry specialist

- Started teaching after 2006;
- Y7, 25 pupils, mixed ability

Lesson topic	Global warming and polar bear extinction (biology)
HSW-related activity	Group work, preparing to introduce the group's video (made last lesson; drama and role-play encouraged), watching all video's, pair-wise peer assessment, criteria from level ladders. Scripts adapted on basis of peer assessment. Hangman game for terminology.
HSW statement(s)	1c, 3a, 3c, 4a, 4b

Teacher C1, physics specialist

- Started teaching before 2006; "changes-certainly", pioneering;
- Y10, 17 pupils, medium/high ability

Lesson topic	Radiation for Life, properties and uses of radiation (physics)
HSW-related activity	Produce a double page centre feature for a fictitious magazine, "Radioactivity Herald". Circulation: schools and colleges, GCSE C-grade and up. Contains features about historical figures, competitions and advertising. Design layout and content of double page magazine spread using Microsoft Publisher (or equivalent). Use your imagination and be creative.
HSW statement(s)	2b, 3a, 3c, 4a

Teacher C2, chemistry specialist

- Started teaching after 2006;
- Y8, 26 pupils, high ability

Lesson topic	Conservation of mass (chemistry)
HSW-related activity	Prepare for courtroom drama (role-play, group work): judge to accuse defendant and explain charges, accused to explain what actually happened, lawyer(s) to present evidence to defend accused. Example defendant: copper accused of putting on weight during burning, therefore breaking the law of conservation of mass. Posters made to collect and present the evidence, chemical model kits available.
HSW statement(s)	1b, 1c, 2a, 3a, 3b, 3c

Teacher C3, biology specialist

- Started teaching before 2006; "changes-certainly", embracing;
- Y10, 12 pupils, BTEC

Lesson topic	EM spectrum – The Eye (physics)
HSW-related activity	Practical with ray boxes and convex and concave lenses; safety: bulbs get hot, do not turn power packs >8V. Use pencil to draw diagram as modelled on board. Use correct terminology: converging and diverging. Research and label diagram of eye. Demo of eye dissection. Relate to job of optician.
HSW statement(s)	2b, 2c, 3c, 4a

Teacher D1, physics specialist

- Started teaching before 2006; "changes-certainly", embracing whole-heartedly
- Y10, 20 pupils, medium/high ability, triple science

Lesson topic	Individual projects, across all three sciences, working towards CREST Award
HSW-related activity	Work together as appropriate (some projects are pair work), research, practical investigation if appropriate, poster making, presentation, organising materials, write-up, keeping individual log book of process
HSW statement(s)	1b, 1c, 1d, 2a, 2b, 2c, 3a, 3b, 3c, 4a, 4b

Teacher D2, biology specialist

- Started teaching before 2006; "doing-some-already-but", following;
- Y7, 25 pupils, mixed ability;
- Observation took place *after* interview

Lesson topic	Materials – elements and atoms (chemistry)
HSW-related activity	Periodic Table, elements; samples of elements (and a few compounds) distributed for observation; record name, symbol and observed characteristics (properties)
HSW statement(s)	2b, 2c, 3c

Teacher E2, chemistry specialist

- Started teaching before 2006; "changes-certainly", following;
- Y13, 12 pupils, high ability;
- Interview took place a few days after observation

Lesson topic	Redox – battery technology (chemistry)
HSW-related activity	How we can apply redox to battery technology, advantages and disadvantages of three types of cell; history of development of first battery/cell; groups research the three different types through documentary evidence – looking for information on how they work, examples, redox processes and equations, environmental/social/economic issues; practical to look at a rechargeable battery (lead, effectively a car battery – safety reminder), thinking through the application of the battery and its suitability for its uses.
HSW statement(s)	2b, 2c, 3a, 3d, 4a

Teacher G1, physics specialist

- Started teaching before 2006; "doing-already", pioneering/embracing
- Y10, 22 pupils, high ability, triple science

Lesson topic	Reflection and refraction (physics)
HSW-related activity	Graph drawing skills (from practical last lesson), calculation of gradient, terminology, use pencil. Conclusion of experiment modelled on board. Link to diamond. Apply calculation to different material. Analogy to explain light slowing down when entering material from air. Diagram to model effect. Anecdotes.
HSW statement(s)	1c, 3a, 3b, 3c

Teacher H1, biology specialist

- Started teaching after 2006
- Y9, 20 pupils, high ability, triple science

Lesson topic	Investigating osmosis (biology)
HSW-related activity	Writing up 'Materials&Methods' in preparation of practical part of investigation, after research into possible methods (previous lesson). Concentrating on variables and terminology. Evaluating possible methods. Demo cork borer. Discussion of Health and Safety. Writing model does not have to be followed to the letter.
HSW statement(s)	2a, 2c, 3b, 3c

Teacher I1, chemistry specialist

- Started teaching before 2006; "doing-some-already-but", following/embracing;
- Y13, 11 pupils, high ability
- Observation took place *after* interview

Lesson topic	Equilibrium (chemistry)
HSW-related activity	Setting up experiment to determine equilibrium constant, to be analysed next week. Teacher assigns each pupil a set of concentrations, leaves pupils to take responsibility for determining densities of liquids. Discussion of Health and Safety, expected variation. Theory of equilibrium (some history and application/implication of Haber Process), with exam practice. Anecdotes.
HSW statement(s)	1a, 1b, 2a, 2b, 2c, 4a, 4b

Teacher K1, biology specialist

- Started teaching before 2006; "doing-already", pioneering;
- Y13, 10 pupils, high ability;
- Interview at lunch time between lessons with the same group

Lesson topic	Photosynthesis – double lesson (biology)
HSW-related activity	Definitions bingo (revision). Building up diagram of parts of photosynthesis; terminology; link with local historical scientist; stresses that diagram is representation/model. Exam practice. Practical: extracting pigments from leaves for chromatography; stress that not all teacher says may be absolute truth, follow instructions without extra input from teacher, work in pairs, safety. Anecdotes.
HSW statement(s)	1c, 1d, 2b, 2c, 3a, 3c

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