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ABSTRACT

'Scientific Investigation' was the first of the four Attainment Targets which prescribed the science component of the national curriculum in England and Wales in 1991. Following a brief historical account of the origins of scientific investigation as a curriculum objective, this paper comments upon the attempt by the central government to define a philosophy of scientific inquiry for the purposes of teaching and assessment and explores the response of science teachers to it. It also examines the implications of that response for the construction and construal of professional practice within the context of a statutory curriculum and the understanding of the nature of science which science teachers were required to deliver. Contains 43 references. (Author)

Legislating and Assessing Procedural Knowledge in Science

by

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Legislating and Assessing Procedural Knowledge in Science

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'Scientific Investigation' was the first of the four Attainment Targets which prescribed the science component of the national curriculum in England and Wales in 1991. Following a brief historical account of the origins of scientific investigation as a curriculum objective, this paper comments upon this attempt by central government to define a philosophy of scientific enquiry for the purposes of teaching and assessment, and explores the response of science teachers to it. It also examines the implications of that response for the construction and construal of professional practice within the context of a statutory curriculum and the understanding of the nature of science which science teachers were required to deliver.

Teaching scientific investigation: a historical perspective

Teaching something about the nature of science as an investigative activity has long been an important element of the rationale of school science since the subject was first schooled in the mid-nineteenth century. As early as 1867, a seminal report from the British Association for the Advancement of Science expressed no doubt that the principal benefit of teaching science in schools was the development of the 'scientific habit of mind' of 'incalculable value, whatever... the pursuits of after life'(BAAS 1868: xxxix)

In according this primacy to mental training and the scientific habit of mind, the BAAS Report reflected the role which scientific method had come to occupy in the ideology of science itself. The proper application of this method generated knowledge which was 'objective', 'value-free' and useful, although, as the Association was at pains to emphasise, utility was not the yardstick against which such knowledge should be measured The emphasis in the Report on the scientific habit of mind was, therefore, more than an elegant means of meeting the requirement of a liberal education, namely a mental training distanced from utilitarian concerns. It was designed to encourage the future well-being of science and formed an integral part of the social contract developed in the mid-nineteenth century between the rapidly developing scientific community and the society within which it was acquiring an increasingly powerful and influential voice.

In those schools in which science became an established component of the curriculum, scientific education was cast firmly in an instrumental and pre-professional role and, by the last quarter of the nineteenth century, a consensus had begun to emerge its form and content Central to that consensus was the teaching of scientific methods, a cause espoused with remarkable zeal and vigour by Henry Edward Armstrong (Brock 1973). Armstrong's heuristic method significantly strengthened the pre-professional dimension of secondary school science and provided it with a powerful, beguiling, and explicit rationale founded upon the teaching of scientific investigation.

There was, of course, reaction to Armstrong's heurism. There was criticism that in many schools more time was spent in laboratory work than the results could justify (Natural science in Education 1918). There was an attempt, notably in the general science movement, to reconstruct school science education by emphasising the applications and utility of scientific knowledge. There was, however, no serious challenge to the importance of developing 'scientific thinking' as a curriculum objective and, during the so-called curriculum development era of the 1960s, this objective was strongly re-asserted. Supported by references to investigative, open-ended or discovery learning, science curriculum projects in many parts of the world emphasised scientific procedures and attitudes. Students following Chem. Study programmes in the USA were promised that they would 'see the nature of science by engaging in scientific activity' (Pimentel 1960: 1 and Preface). In the United Kingdom, the intention was to get 'pupils to think in the way practising scientists do' or, as the Organiser of the Nuffield Ordinary Level Chemistry project expressed it, 'to learn what being scientific means to a scientist' (Halliwell 1966: 242). 'Scientific Investigation' was one of the categories deployed by the Assessment of Performance Unit during the 1980s and, when the Department of Education and Science published its policy statement in 1985, the essential characteristic of school science education was stated officially to be that 'it introduces pupils to the methods of science' (DES 1985: para.1).

This commitment to teaching scientific investigation is reflected in the form, contents and titles of many recently published texts for use in schools. Examples from the United Kingdom are *Process Science, Science in Process* and *Active Science*. The last of these states with particular clarity 'what it takes' for a pupil 'to be good at science', namely 'communicating and interpreting, observing, planning investigations, investigating and making', together with such basic skills as an ability to 'follow instructions for doing experiments' (Coles 1989: 4-5). The firmest possible commitment, however, is manifest in the science component of the national curriculum in England and Wales and, in particular, the revised version laid before Parliament in December 1991. This version reduced the number of Attainment Targets from seventeen to four and combined elements of two Target in the earlier version into a new first Attainment Target, entitled *Scientific Investigation*, and commonly referred to as Sc1. This Attainment Target legitimised an identifiable and universally applicable method of generating scientific knowledge and stressed the relationships between this method and the scientific content prescribed by the remaining three Attainment Targets. Although the most recent revision of the national curriculum has replaced Sc1 by *Exploring and Investigating Science* and led to important changes in the original 10-point scale of assessment, the commitment to scientific investigation as fundamental to school science education remains essentially unchanged

Some philosophical considerations

The nature of science and, in particular, of experimentation within the scientific endeavour are problematic and contentious matters. Attempts to understand them span several domains of scholarship, notably history, sociology and philosophy. Writing of the history of science in the USA during the first half of the twentieth century, Thackray has commented that 'it displayed the heroic achievements of great scientists of the past' and constituted a 'possible basis for confidence in the continuation of the achievements of the scientists in the future' (Thackray 1981: 450). This characterisation, which is of more universal applicability, reflected the widespread acceptance of a positivistic philosophy which promoted and sustained the notion that science offered an unique route to objective and benevolent truth, derived from the proper application of scientific method. Despite the difficulties presented to this dominant philosophical understanding of the nature of science, notably by the development of relativity and quantum theory, the logical positivism the Vienna circle dominated the philosophy of science during the inter-war years.

However, even during this period, there were significant challenges to both the philosophy and historiography of science. There were attempts to develop a philosophy of science anchored in historical understanding, rather than derived from the dictates of logic, with the work of Bachelard (1958) foreshadowing Kuhn's ideas bout 'revolutionary' and 'normal' science. Within the past thirty years, the framework for constructing the past has had to accommodate not only the 'internalist-externalist debates among historians of science but also the radical contextualist approach which has raised the important question of the extent to which the formulation of scientific knowledge, and not simply the use to which it is put, is determined by developments taking place in the wider social context. It has also had to respond to the ideas encompassed by the so-called 'New History and Sociology of Science' (NHSS) which offer important insights into the generation, replication and validation of scientific knowledge.

As for the philosophy of science, the mixture of Popperian idealism, Kuhnian pragmatics, and its logical extension, Feyerabend's *Against Method* (1971), has done more than highlight the fallibility of science or relativize scientific knowledge, and, thereby, help to diminish the standing and authority of the scientific endeavour. It has also contributed to the evolution in empirical philosophy, marked by the turn from logical models to historical modes of understanding (Hesse 1980). Of more immediate consequence in the present context, it has rendered antique 'the sort of ideology of science which, explicitly or implicitly, has provided coherence and security for generations of (science) teachers (Ravetz 1990: 20) and left those with a concern to promote an understanding of the nature of scientific investigation with no agreed replacement. There is now

> no well-confirmed general picture of how science works, no theory of science worthy of general assent. We did once have a well-developed and historically influential philosophical position that of positivism or logical empiricism, which has now been effectively refuted. we have a number of recent theories which, while stimulating much interest, have hardly been tested at all. And we have specific hypotheses about various cognitive aspects of science, which are widely discussed but wholly undecided If any extant position does provide a viable understanding of how science operates. we are far from being able to identify what it is (Laudan *et al.* 1986 142).

The task facing those charged with prescribing scientific investigation for the purposes of teaching and assessment within a national curriculum was, therefore, formidable. Perhaps inevitably, however, multiple meanings and scholarly insights yielded to the pressing demands of curriculum construction within a framework designed for accountability. As far as Sc1 is concerned, science teachers were advised that their pupils:

> should develop the intellectual and practical skills which will allow them to explore and investigate the world of science and develop a fuller understanding of scientific phenomena, the nature of theories explaining these and the procedures of scientific investigation.

Such development was to take place through progressively more systematic and quantified activities which encouraged the ability to plan and carry out investigations in which pupils

1. ask questions, predict and hypothesise
2. observe, measure and manipulate variables
3. interpret their results and evaluate scientific evidence (DES/WO 1991:3).

Each of theses three strands was amplified at each of the ten levels of attainment. For example, at Key Stage 3, pupils achieving at level 4 could be asked 'to investigate variables which affect the rate at which water cools, identifying temperature as the variable to be measured, the thickness of material as the variable to be changed , and (to) choose appropriate instruments to measure quantities such as the volume of water used, water temperature and cooling time'. At Key Stage 4, level 6, pupils could be expected to consider the factors affecting the rate of a chemical reaction, identify the variable to be controlled, conduct an appropriate investigation, present the results graphically and account for them in molecular terms.

Teachers' responses to Sc1

Except where otherwise stated, the responses referred to in the following paragraphs are derived from data collected as part of a wider study of Sc1 as a policy initiative (Donnelly *et al.* 1993). The data were obtained from a variety of sources. Written sources ranged from statutory publications (DES/WO 1989, 1991) and official, but non-statutory publications (NCC 1989), through professional journals for teachers, to documents produced at school and local authority level. Observations were made and recorded at a number of different sites. These included school science laboratories, where teachers were engaged in teaching 'scientific investigation' or assessing their pupils' competence at it, and both formal and informal meeting held to discuss Sc1. Finally, semi-structured interviews were used to collect data from pupils, teachers, professional subject officers within national organisations and Examining Groups, and from some of the science educators involved in the development of the assessment arrangements for Sc1. Thirty one teachers, drawn from ten schools in different parts of the country were interviewed between October 1993 and march 1994. The teaching and assessments of Sc1 in schools was also closely observed, the schools themselves being chosen partly at random and partly upon the advice of science educators invited to locate high quality work in this aspect of the national curriculum. The teachers' responses in interview proved consistent with the opinions expressed by the much larger numbers of their professional peers attending inservice and other meetings concerned with Sc1. Data were also obtained from a subsequent round of interviews (including some reinterviews) conducted in June/July 1994. This introduced additional schools and teachers to give a total sample size of 38 teachers and 23 pupils.

The incorporation within the national curriculum for England and Wales of an Attainment Target concerned with scientific investigation can be regarded as a statutory codification of a long-standing curriculum commitment to 'finding out' or discovery, based upon experimentation as a means of generating new knowledge and understanding of some aspect of the natural world. To this extent, therefore, science teachers might be expected to have welcomed scientific investigation, if not necessarily its interpretation as Sc1, as reflective of a fundamental and established feature of their professional practice. There is some evidence that this was the case, a survey conducted by the Association for Science Education in 1993 concluding that many of the respondents were very positive about investigations and regarded them as at the heart of all good science teaching (ASE 1993a).However, given the lack of any fundamental agreement about the nature of scientific investigation, problems were inevitable. These problems were compounded by the fact that only a small minority of science teachers had any direct experience of involvement with scientific investigation as a research activity. Most, therefore, were called upon to teach a curriculum component which despite its rhetorical resonances with investigative pedagogy or discovery learning, was unfamiliar to them.

> Basically, none of us understood (scientific investigation), so we had to go away and find out all about it.
>
> (Scientific investigation) is as much a learning process for teachers as it is for children.

In seeking clarification of what the authors of the national curriculum intended by 'scientific investigation', science teachers looked to the Statutory Order itself and, in particular, to the assessment framework elaborated for Sc1. Further insights was sought from the variety of training days, inservice courses and publications about Sc1 that collectively soon came to constitute a minor industry. Quasi-official guidance from the School Examination and Curriculum Authority (e.g. SEAC 1992, 1993a, 1993b) was supplemented bye other material generated principally by local education authorities, the Association for Science Education, the Examination Boards responsible for assessment at Key Stage 4 and, in the later stages, commercial publishers. The time devoted at the Annual Meeting of the Association for Science Education to lectures, symposia, workshops etc. concerned with Sc1 rose, as a proportion of the overall programme, from 2.8% and 2.7% in 1991 and 1992 respectively to about 8% in each of the following two years (Buchan 1995). The anxiety of teachers and others about what was being asked of the teaching profession in teaching and assessing 'scientific investigation' was also reflected in correspondence in the professional press, where critical letters or articles sometimes prompted eccentric and defensive responses at a time when what was need was informed professional debate, e.g.

> Too many voices shouting too soon about aspects of Sc1 being unworkable are more likely to endanger the very position of practical investigation in science education (TES 1993a)

Negative messages about scientific investigation could have damaging effects on science education (TES 1993b)

For many science teachers, inservice courses and much of the published material relating to Sc1 initially enhanced, rather than diminished, their concerns about teaching and assessing this component of the national curriculum. In the absence of a significant body of experience of such teaching and assessment upon which those offering training programmes or providing exemplar material or advice might have been able to draw, important differences in interpreting aspects of an innovative curriculum component were inevitable. The frustration of many science teachers attending inservice courses concerned with Sc1 has been well-captured by Buchan (1995). she refers to 'heated exchanges' between teachers and trainers at sessions organised by the Examining Groups and to the teachers' sympathy with some of those trying to assist them.

They (the Examining Groups) have been stumbling their way like everybody is stumbling their way through to try and generate material (Buchan 1995: 94)

Some of the teachers' frustration touched upon matters of a more fundamental kind.

All you tell us is basically against everything we have learnt. (Buchan 1995: 93)

Examining Groups, responsible for assessing pupils' work at Key Stage 4 (16+), undertook work jointly with the School Examinations and Assessment Authority to 'provide exemplification of the standards for assessing coursework in GCSE science' (NEAB 1993: 3). However, teach··s did not always find it easy of possible to reconcile this exemplification with the understanding of Sc1 which they derived directly from the Statutory Order or from other sources. These sources included local education authorities, some of which worked with teachers in their employ to produce appropriate curriculum materials. These materials were often highly derivative, both in terms of their suggested topics for investigation and in their reference to the terminology (suitably re-worded for pupils to read) of the national curriculum e.g.

Asking questions in science.
At Level 2, I can ask why something happens. I can *predict* what might happen in my investigation.
At Level 3, I can use my own ideas about things I have seen to think up investigations.
At Level 4, I can use some ideas I have learnt in science to think up an investigation.

Although materials of this kind were often well-produced, they were not always well-received, one teacher (who abandoned them after a first attempt to use them), comparing the sheets produced for pupils to record their work in Sc1 with 'social security benefit claim forms', the pupils spending hours trying to fill them in. The large-scale generation at school or local authority level of tightly structured work sheets to teach and facilitate the assessment of scientific investigation was, of course, only one of a number of organisational responses to the assessment requirements of the national curriculum.

The Statutory Order itself was also not without uncertainties and ambiguities. The requirement that pupils distinguish between generalisations and predictive theories was difficult to interpret , and the distinction itself, presented in the national curriculum as unproblematic, is the subject of much debate among epistemologists. There were also difficulties within the assessment structure of the Attainment Target, notably at the upper levels. At Level 8 of Key Stage 4, pupils were required to 'use scientific knowledge or theory to generate quantitative predictions and a strategy for investigation'. This is not easily distinguished from the corresponding Level 9 requirement that pupils 'use a scientific theory to make quantitative predictions and organise the collection of valid and reliable data', although a distinction might be made on the grounds that the level 8 statement entails no judgement about the quality of the strategy which the pupil develops. Equally, however, it might be claimed that any approach properly described as a 'strategy' involves much more than the collection of reliable and valid data, with the consequence that the performance at Level 8 represents a higher level of achievement than at level 9 in supposed hierarchy.

Difficulties of this kind were addressed in a Circular, sent to headteachers and highlighting the key features of scientific investigation at the higher Levels. Produced by the School examinations and Assessment Council (SEAC 1993a), the Circular carried a status that can be described as quasi-official. It could not supplant the Statutory Order but it was perceived by teachers as another layer of 'government interpretation' of the legal definition of Sc1. Interestingly, the Circular ignored the three strands of Sc1 identified in the Order and offered specific differentiating features between adjacent Levels of attainment. For example, Level 8, referred to above, was said to require the investigation of 'more than one aspect of a question or problem', an interpretation far from obvious in the Order itself. It is, of course, acknowledged that any written statement must under-determine practice and that the meaning of the three remaining Attainment Targets of the science component of the national curriculum also needed to be negotiated. However, Sc1 differed from these other Targets in several important respects. It was largely a construct of the national curriculum and lacked an adequate foundation in the professional training and practice of the science teachers who were responsible for its entirely school-based assessment. In addition, it was meant to be integrated with the other Attainment Targets for assessment purposes. In these circumstances, the need for clear guidance, adequate training and time for professional discourse was overwhelming, and the concern of the teachers understandable, as they sought tore-shape their professional practice in response to the demands being made upon them. The notion of 'accountability' was also important for some teachers.

> I want to know exactly what it is you want me to teach...because someone, some day is going to say to me "Have you done it?" and I want to be able to show that I have.

Equally understandable, although not sitting entirely comfortable alongside the claim that 'Investigative work is seen as an important part of students' science education '(ASE 1993:5) was the strong sense among science teachers that the burden of responsibility for, and knowledge in relation to, Sc1 lay elsewhere than with them. Typically, the generation and definition of the Attainment Target was seen as having been done by 'mysterious figures', 'a professor or somebody who had been sent away for a weekend to do this', people up there' (i.e. in government) or 'those in authority'.

> We were suddenly presented with a whole new framework for practical science....and told to get on with it.

The implication of comments such as these was that:

> ....if this whole thing had been our idea, it would have been different. None of it was our idea, not any of it, it was all government decision and they appointed people to do this. What they have done is....come up with paperwork with fantastic ambitious ideas and they have not managed to put any of it into schools in a usable form. They can't because we are not on the same wavelength.

A corollary was that curriculum development was shifted 'away from teachers who are the ones who should be managing the development themselves'. Science teachers found themselves 'desperately trying to make Sc1 work for them', instead of confronting government at an earlier stage and saying:

> (This) is rubbish. Go back and change it until it is something we can implement.

Comments of this kind from teachers about the origins, ownership and practicality of Sc1 were often coupled with an abiding commitment to the importance of investigation in science education. For some science teachers, what was at issue was control over their own professional practice.

> I can't understand.. why science teachers have allowed the wool to be pulled over their eyes. ..We didn't take a professional stance

> Structures of responsibilities have changed....Some people are seen as providers and others as deliverers.

> Who said we were still professionals?

Some science teachers speculated on the motives of those responsible for the inclusion of scientific investigation as an Attainment Target in the national curriculum. The lack of agreement about motives among the science teachers is itself of some significance.

> I think it is....an encouragement for people to do more practical work.

> When I was teaching in the '60s and '70s... there was quite a lot of practical work but it was all recipes Never did the (pupils) make their own hypothesis.

> I think it's because we are trying to teach people to be scientists and this is one way of measuring a person as a scientist.

These perceptions by teachers should be set alongside the following comments from members of the Working Party which had, in effect, constructed Sc1.

To us on the Working Party, skills of investigation was a main signal about the flavour of what science was about....We tried to see....investigatory science as really fulfilling several functions....(developing) the skills needed to do science, motivating learning and as an example of what we believed to be....the best aspects of learning in general.

Everybody knew in principle (scientific investigation) was important, but no one knew how to describe it, and so it nearly didn't exist at all....but in the end we got a version....Looking back, it was rather a sort of Pandora's box of bits and pieces

I was some time before the concerns and perceptions identified above came to be acknowledged and discussed openly within the science teachers' professional organisation, the Association for Science Education (ASE). When the plans of central government for a national curriculum were first announced, the ASE might have challenged the competence of those appointed by government to legislate the professional practice of most of its members and it might have sought to distance itself from the national curriculum and adopt the role of informed professional critic as events unfolded. The close involvement of a number of prominent members of the Association in the first Science Working Party set up in 1987 to advise government upon the content of the science component of the national curriculum perhaps made direct criticism of that component more difficult, but members of the ASE were alerted to the wider issues involved in a letter published in the Association's Bulletin, *Education in Science*. Chapman, writing in 1990, commented that the ASE seemed, 'through the involvement of its leading members and officers, to have allowed itself to become too closely identified with approving....the inherent totalitarianism of centralised curriculum control'. For Chapman, the national curriculum threatened to reduce science teachers to 'curriculum postpersons', charged with 'delivering whatever is put in their postbags by those employed to do the government's bidding (Chapman 1990: 39). However, Chapman's view seems to have commanded little in the way of support, although the correspondence pages of the ASE Bulletin are necessarily a limited and selective indication of wider opinion. Responding to Chapman's letter, Martyn Berry advised that the 'ASE must....speak out far more loudly and more often about the true aims of science education and the need for an independent, fully professional teaching force' (Berry 1990: 38-9). Another member of the Association, lamenting that he had 'felt increasingly distanced from the ASE editorially, and in the content of many of the articles published', commented that 'At long last the ASE is publishing, albeit only in its correspondence column, something which reflects the concern of the majority of teachers' (Hennessy 1990: 37)

The Association did not respond publicly to these opinions expressed by individual members and subsequent action suggests that they were ignored. Its stance, which might be summarised as 'assisting members to deliver the national curriculum' was one which was to cause the ASE and its members some difficulty when the revised Order, incorporating Sc1, was published in December 1991 and given the effect from 1st August, 1992.

At the Annual meeting of the Association in January, 1993, dissatisfaction surfaced among the membership over this stance. Comparison was made with the National Association of Teachers of English (NATE) which had confronted the government over both the content of the English component of the national curriculum and the associated testing procedures. Unusually for an ASE Annual meeting, a resolution was prepared by eleven members, circulated to those attending the Meeting and placed before the Annual Business Meeting on the Sunday morning. The resolution called upon the Council of the Association to 'take urgent steps to assess the damaging impact of the rushed implementation of KS3 and KS4 and to advise members of the action required to prevent further damage to students' learning and enjoyment of science' (Carlton and Kinsman 1993).

Although this motion was unsuccessful, it prompted the ASE to seek the views of its members about the development of the science curriculum. Using a double-sided A4 questionnaire, members were invited to comment upon a wide variety of issues, including the use ('seen, read/used, helpful, unhelpful') which they made of official and ASE publications and how the latter might further assist them in their work. There is uncertainty about the size and composition of the sample of members who completed the questionnaire but it is likely that less that 1 per cent of the membership expressed an opinion Nonetheless, among the responses, concern about SC1 was a dominant feature. The ASE was urged to give greater prominence in both its journal, *The* School *Science Review*, and the more-frequently published *Education in Science* to 'samples of pupils' work for Sc1 with marks', 'advice on interpreting Sc1 criteria', and 'short, snappy articles giving practical advice'. Although the centrality of scientific investigation in the science component of the national curriculum attracted some support, most ASE members emphasised the pedagogical and assessment difficulties of implementing Sc1 and drew attention to the stress and uncertainty experienced by both science teachers and their pupils. Some identified 'more time', 'more training' and 'better support material' as ways of easing their difficulties. Others urged reform or even abolition of Sc1. Overall, the attitude of the ASE members who responded to the questionnaire was strongly negative, with over half the respondents classifying this Attainment Target as a problematic curriculum initiative (ASE 1993b).

In May, 1993, the ASE acknowledged that the 'majority of concern' expressed in the questionnaire related to Sc1 and undertook a further survey to identify more specific ways of helping its members. More particularly, the survey sought to gather detailed views from teachers 'regarding the problems they perceived in delivering Attainment Target 1 of the National Curriculum for Science', and to 'gain a clearer understanding of how science teachers thought science education in schools might be supported more effectively by the scientific industries'. The questionnaire was designed and printed by British Nuclear Fuels which also undertook to analyse the data and prepare the report The questionnaire, sent by the ASE to 2,500 primary and 2,500 secondary school teachers, generated a 23 per cent response by the end of the summer term of 1993. Of the 1,145 respondents, 698 and 413 members were teachers in secondary and primary schools respectively. Asked whether 'Sc1 is the most important of the 4 Science Attainment Targets' 80 per cent of the primary teachers agreed that this was so, with half of these expressing 'very strong agreement'. Among the 698 secondary school science teachers, only 25 per cent supported the privileged status of Sc1. Unfortunately, the survey did not explore respondents' reasons for their opinions and the report could only conclude, rather lamely, that 'it is interesting....that teachers. mostly qualified in core science subjects feel Sc1 to be less important than those with mostly other teaching qualifications who may be having difficulty in delivering this area of the curriculum'. In the absence of firm data, it is perhaps legitimate to speculate that the difference between the primary and the secondary teachers, while it may be related to qualification, also derives from the greater emphasis in primary pedagogy upon skills, processes and 'child-centred learning', at the expense of scientific knowledge acquisition. It is also interesting to note that both primary and secondary teachers in the survey found Sc1 'more difficult' than the remaining three Attainment Targets and judged that science teaching would 'deteriorate' if 'Sc1 were not delivered satisfactorily' (ASE 1993c: 6).

This greater difficulty is reflected in the opinions recorded by schools inspectors following their inspection of science lessons. In 1992-3, standards in scientific investigation were said to 'remain lower that for other Attainment Targets' at Key Stages 3 and 4, although som high standards of investigative work were 'beginning to emerge' (Ofsted 1993: 2). The following year, the Office of Her Majesty's Chief Inspector of Schools again reported that 'In Key Stages 3 and 4 levels of achievement in Attainment Target 1 are lower than in the other Attainment Targets', adding that there was also greater variation between schools in this aspect of their work (Ofsted 1994: 3).

Educational policy and the reconstruction of professional practice

The centralised, 'top-down' approach to educational policy represented by the national curriculum in England and Wales has received attention from scholars working within a number of different research perspectives. Some (e.g. Ball 1990, Kogan 1975, 1983) have focused their attention on the shaping of educational policy as a political response at national level to a variety of social, economic or interests. There is a corresponding and complementary literature concerned with the 'implementation' of national policy at some appropriate level (e.g. Gleeson 1989, Saunders 1985). However, two assumptions are noteworthy in these approaches. The first is that policy making and policy implementation can be sharply distinguished. The second is that it is possible to determine a central educational policy relating to the curriculum or assessment that is unequivocal and unproblematic. Both of these assumptions present difficulties and both have important consequences, not least for those with research interests in educational policy. For example, by presenting policy as an essentially linear process, the distinction between policy making and policy implementation promotes a dichotomy between 'theory' and 'practice' and privileges the former over the latter. It also encourages the notion of 'policy subversion' in which teachers, or others, 'subvert' policy, for example, by appropriating it for purposes very different from those intended by the policy makers. Such subversion/appropriation is much in evidence in the literature concerned with the response of schools and local education authorities to the Technical and Vocational Education Initiative (e.g. Saunders 1985, McCulloch 1986, Dale *et al.* 1990).

In the case of Sc1, the evidence presented above suggests strongly that it is inappropriate to regard policy, formulated as a central government directive about the nature, teaching and assessment of scientific investigation within the school context, as something centrally promulgated and then subject to drift, subversion, or, depending upon one's perspective, appropriation and subversion. Arguably, the greater role in originating and sustaining policy in teaching and assessing Sc1 lay not with central government but with schools, Examining Groups, the Association for Science Education and the teachers themselves. In these circumstances, policy becomes a function that, far from being centrally controlled, is delocalized and differentiated.

More is involved here than the observation that 'Practitioners do not confront policy texts as naive readers' (Bowe *et al.* 1992: 22) and its corollary that curriculum or assessment policy is contested, negotiated and realised by divers individuals functioning in different contexts, each with its own legacy of experience, interests, values and sense of purpose. Central to the understanding of policy realisation presented here is the professional practice of science teachers and, in particular, the notion of 'professional judgement'.

This notion was frequently invoked when teachers sought advice on how to deal with the many uncertainties with which Sc1 presented them. Such invocation seems, at first sight, to challenge the sense of de-professionalism and de-skilling to which reference has been made above, since it recognises both the independence of science teachers and the indeterminate elements within their practice. However, two key aspects of the implementation of Sc1 contradict this. The first was the insistence that the activities undertaken by pupils for assessment purposes must meet specific and centrally-defined characteristics, pre-eminent among which was the requirement that these activities involve self-generated entire investigations. There was not general recognition by policy makers that teachers might have views on the value and practicability of this requirement, and where such views were acknowledged, they were dismissed. The negative judgement made by teachers about Sc1 came to be represented as, or were assumed to be, wrong or misdirected, rather than valued as contributions to a professional debate. The second aspect which indicated a thrust towards de-professionalization was the stream of *ad hoc* guidance, addressing specific issues within Sc1 and illustrated above. This was a consequence of widespread uncertainty and ignorance, among teachers and others involved in science education, about the structure of Sc1 and what could or 'ought' to be taught and assessed within it. It was when such guidance failed, as it frequently did under the weight of the self-imposed task of seeking to construct a codified, bureaucratised version of 'the process of scientific investigation', that the rhetoric of teachers' professional judgement came into play.

An associated claim that the emphasis on investigation represented by Sc1 merely reflected a widespread element within the existing practice of science teachers is untenable. Sc1 involved not a consolidation of existing practice but an attempt to impose curricular change by statutory means. It also involved a contradictory and fractured perspective on the role of teachers, within which it is possible to see their putative professional status and their competence to decide matters of educational practice simultaneously exploited and dismantled. Ultimately, however, the difficulties underlying teachers' responses to trying to teach and assess scientific investigation within the context of the national curriculum reflect the lack of a coherent and common perspective on their professional relationship to, and authority over, their own practice in laboratories and classrooms.

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