Assessment of practical and enquiry skills: lessons to be learnt from pupils' views

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14 to 16 year-old pupils can provide some valuable insights into how assessed science investigations are, and could be, conducted in secondary science

The first attainment target (Sc1), of the Science National Curriculum for England and Wales, *Scientific enquiry*, has embedded investigative work in school science as one of four statutory attainment targets for all pupils in the age range 5–16 since 1989. The intention was to unify disparate approaches to investigation and to make scientific enquiry an integral part of pupils' learning experiences, but research studies suggested that there was a gap between policy and practice. New criteria for key stage 4 (which informed specifications for syllabuses from September 2006) aim to bridge the gap. The criteria state that any specification should appropriately develop pupils' skills, knowledge and understanding of how science works and that all pupils should develop a critical approach to scientific evidence and methods. This article provides some insights into the views of 14–16 year-olds about the assessment of science investigations at key stage 4, which may inform curriculum development in schools.

ABSTRACT
This article reports research into the views of pupils from nine state-maintained secondary schools about assessed investigative work at key stage 4 (14 to 16 year-olds) in the English National Curriculum. It presents a discussion of pupils' views about the role of the teacher, the timing of investigations in relation to curriculum content, time allowances and apparatus provided. Conclusions relating to the conduct of assessments of practical and enquiry skills in school science are discussed and how the opportunities of the new National Curriculum from September 2006 may be realised.

Problematic aspects of assessment of key stage 4 science investigations, part of the GCSE (General Certificate of Secondary Education) examination, have been identified. Gott and Duggan (2002: 194) found that 'routinisation' resulted where teachers used a limited number of investigations to ensure reliability in assessment of investigations. Roberts and Gott (2003) suggested that a skills-based approach to assessment of investigations was a performance model, which doesn't properly assess pupils' ability to investigate but encourages them to perform. Since pupil achievement is not assessed directly, but by pupils' written work, mismatches between some pupils' ability to design and carry out an investigation and their ability to produce a good report can occur. Another problem may be a variation in pupil performance between one investigation and another, depending on the subject matter, context, openness or complexity of the problem.

Pupils' views also related to a performance model in a major QCA (Qualifications and Curriculum Authority) survey, involving teachers and pupils, about secondary school science (Nott *et al*., 1998). For key stage 4 pupils, investigation was more about '*getting a good mark*' than learning or understanding science, and a clear majority felt sure that they knew how to get good marks in Sc1 at GCSE (Nott *et al*., 1998: 30). Pupils had a rigid view of practical work as routines to be completed correctly and completely in a limited time. The survey revealed that just over half the pupils felt there was less practical work at key stage 4 than earlier.

Using a narrow range of tried-and-tested investigation examples has been criticised by Watson, Goldsworthy and Wood-Robinson (1999) and Osborne (2004) and has been highlighted in a House of Commons report:

> *The way in which coursework is assessed for GCSE science has little educational value and has turned practical work into a tedious and dull activity for both students and teachers.* (House of Commons Science and Technology Committee, 2002: 21).

Keiler and Woolnough's (2002) report of research carried out among key stage 4 pupils in one school showed that pupils recognised the domination of investigations by assessment. Pupils' motivational behaviours during practical coursework were of six types: implementing correct procedures; following instructions; doing what is easy; acting automatically; working within limits and earning marks.

The present research further examined pupils' views about their experiences of science investigations. Interview data were gathered from 51 pupils from a total of nine schools across two English counties, during the period when they were in years 10 and 11 (ages 14 to 16 at key stage 4 of the National Curriculum). The main issues, which arose from collaborative analysis of the data using the canons of 'grounded theory', are discussed here as part of a wider discussion of practical and, in particular, investigative work in school science. Throughout this article the term 'coursework' will be used to refer specifically to coursework for assessment as part of the GCSE examination.

The main issues

Role of the teacher

The intention for coursework assessment was to help the teaching and learning process by encouraging and measuring skills not easily tested in examinations and that would involve practical skills. However, pupils remarked that teachers seemed to train them to do investigations:

> **Iona:** *Which is a bit of a shame in a way really because its been sort of, 'Well this is what you have to do'. And then you automatically have to 'yes', parrot fashion. It does affect us because all the teachers and everyone are aware that you should get a good mark.*
> **James:** *It was like ... They trained us to do investigations and we don't need to do any more.*

Pupils thought that one way in which teachers trained them was by encouraging repeat data collection, although pupils often did not seem to understand the purpose:

> **Kwesi:** *But ideally we'd have a hundred, a hundred different results.*

Teachers were also seen to train pupils to comment upon anomalous results. Several pupils thought that anomalous results were desirable. For example:

> **Penelope:** *Something in the experiment went wrong but it was quite good we had one of those because we could explain.*

The use of investigation solely as summative assessment continues in many schools. It seems that pupils do not understand that investigation is integral to science learning, but perceive it to be an assessment strategy separate from learning, rather than the more realistic view that science is predicated upon investigation.

In contrast, pupils in one out of the nine schools described science learning through an investigatory approach:

> **Katy:** *The teachers have done loads of practical with us and they try to keep us involved. We have done loads and loads of investigations.*
> **Halima:** *We have done practicals all the way through. I think we have definitely got the idea of science as a practical subject, but you have to know a lot of theory first!*

In this school, teachers integrated investigation into the scheme of work for GCSE courses. These pupils frequently investigated in science throughout key stage 4, as opposed to having separate investigations for assessment; pupils received feedback and teachers selected the best work for submission as coursework:

> **Jonathan:** *We do loads of experiments and we have to do investigations right the way through and then the teachers pick the best ones.*

Pupils' perceptions were confirmed by the head of science, who described how she stimulated investigations from standard illustrative experiments such as the action of acid on metals. The spirit and letter of the National Curriculum were followed, with subject content being taught through, and not separate from, investigation.

Science coursework is intended to assess investigative skills that have been developed during the GCSE course and involves the application of knowledge and understanding, analysis and evaluation. We have found that many year 10 and 11 pupils (14–16 year-olds) regard teachers as complicit in training them to repeat results and to look for anomalies so that marks can improve, without an understanding of reliability and validity or the significance of anomalies. Pupils' comments about anomalies extend Keiler and Woolnough's (2002) report in which pupils' ways of earning marks included a focus on more complete explanations, including graphs, which even resulted in falsifying results. Pupils did not see their teachers as disengaged from the process of assessment as has been implied (Osborne, 2004), but in all except one school they seem to be saying that their teachers have disengaged investigations from the rest of the science curriculum.

Timing

In previous research (Nott *et al*., 1998; Osborne and Collins, 2000), pupils commented that there were fewer opportunities presented for practical work in years 10 and 11. This was confirmed and extended in the present work: pupils expressed their disappointment that the final summative piece of assessed coursework, completed by the end of year 10 or the beginning of year 11, usually marked the end of practical work altogether:

> **Lindsey:** *We did a lot of experiments until about the middle of year 10. Then we did investigations.* **Becky:** *We don't do much practical any more. We did the investigations and it seemed to be that we were tested on our practical so that was that.* **Jonathan:** *We used to do a lot of experiments but not any more. Since we did our last investigation they seem to be cramming in all the theory.*

Some pupils thought that things could be different:

> **Katherine:** *We should do little projects so that you are working for yourself and not for the teacher.* **Kieran:** *More practical, more projects. I think we should do far more in year 11. After you do your investigation you should be good at practical.*

The criticisms from pupils in this study seem to show that to learn about how science works by enquiry, exploration and application is not commensurate with the almost complete cessation of investigations half way through the GCSE course. Apart from one school in which investigation was used as a learning tool throughout the science programme of study, the majority of schools used it for assessment only.

Time

In most of the schools in this study, pupils' complained about insufficient time for collecting and considering results, illustrated by the following comments:

> **Iona:** *We were one of the most efficient groups and we barely just got the whole thing done.* **Melanie:** *If you talk to other people while you're doing it, the main thing you are worried about is the time and that was just what they was thinking about rather than thinking 'what conclusions can I draw?'*

These concerns appear to be a consequence of teachers' choices, reported by Nott *et al*. (1998), of investigations to maximise marks for coursework, which could be completed quickly in small 'windows' of time. Opportunities for 'thinking time', where pupils can engage in discussions about the questions they pose and reflect on their data, conclusions and evaluations away from busy laboratory activities, may need to be planned. The Assessment and Qualifications Alliance, in its examination report (AQA, 2002), responds to the argument that there is insufficient time for investigative science, by pointing out that science taught through an investigatory approach brings relevance, opportunities and rewards and, as discovered in this research, a realistic view of science as a practical subject.

Apparatus

There were several concerns about apparatus in science investigations. The first was about the amount of equipment provided:

> **Christine:** *I was thinking, they don't have enough equipment. 'Cause we had to ... we couldn't start our experiment. We had to keep pressurising this man [technician] to get on.*

The second was about the dependability of the equipment:

> **Richard:** *We do less practical in chemistry and biology and the equipment doesn't work too well.*

There were also a number of comments about the pupils' lack of familiarity with apparatus used for investigations, since much equipment had not been used routinely, for example:

> **Iona:** *A lot of the equipment we hadn't worked with before that.*

Pupils' criticisms about insufficient equipment in both quality and quantity are understandable given the limited resources in many school science departments. However, the head of science in one school described a greater range of investigative work with more open-ended opportunities, instead of a limited number of 'set piece' investigations; this reduced the need for large quantities of similar and often unfamiliar equipment. The new specifications encourage pupils to become familiar with new equipment and to develop the necessary manipulative skills. The formative assessment of procedural understanding using the type of pencil-and-paper tests discussed by Roberts and Gott (2004) may prove, we suggest, to be a useful tool if used prior to practical investigations. In some schools, the 'family silver' store of reserved apparatus, only brought out for infrequent investigative work, is an area that needs further examination.

Conclusions

Our research gives prominence to pupils' voices and provides evidence that they see little benefit in being trained to do a limited range of investigations at key stage 4. This situation seems to have arisen from a culture of high-stakes assessment, where a difference between a GCSE grade D and a grade C is critical for comparing school with school and has had the widespread effect of conflating the teaching and summative assessment of investigation.

We have analysed the approved specifications for GCSE courses published by the four awarding bodies, based on the key stage 4 National Curriculum programme of study and the GCSE criteria for science, commencing September 2006. An analysis of the internal (teacher) assessment procedures indicates a mixed set of interpretations. Teachers must be careful when considering suggested 'typical' investigations (AQA, 2005: 69) that we are not simply replacing the resistance wire investigation from the previous GCSE with newer investigations such as the efficiency of an immersion heater. Most awarding bodies, in providing an assessment framework for GCSE science, suggest specific, practically based tasks that seem to encourage a return to the 'set piece' investigations of the past.

One of the four awarding bodies allocates ten per cent of internal assessment marks to practical skills such as taking readings, presenting data and following instructions (Edexcel, 2005). This approach recognises Gott and Duggan's (2002) contention that skills such as planning, observation and measurement can be taught and practised, whereas effective problem-solving requires conceptual as well as procedural understanding. However, this performance model risks being applied more generally to investigation where published assessment activities are included in awarding body specifications.

Unlike previous versions, the 2004 science National Curriculum for England does not use the terms 'investigations' or 'investigative work', but uses the terms 'problem', 'question' and 'enquiry' as part of the rubric for practical and enquiry skills, which strongly point towards open-ended practical work. Awarding bodies, by prescribing lists of practical assessment activities, seem to be narrowing the range of possibilities for authentic enquiry. This may be a response to explicit statements about the collection of data from primary and secondary sources and the return to the terminology of validity and reliability last seen in the early 1990s. Some specifications encourage teacher decision-making about the practical procedures chosen for data interpretation and evaluation and are sufficiently open-ended to allow professional judgement by teachers (OCR, 2005; WJEC, 2005: 67), whereas other specifications appear to be more prescriptive.

In the past, the requirements of awarding bodies to both internally moderate within schools and to externally moderate between schools, have made tried-and-tested summative investigations seem more attractive than new ones. This approach, which leads to excessive workload borne from years of prescription, is one interpretation of the regulations inferred to be prevalent in most schools in this study, but antithetical to the spirit of investigation.

This research has shown that investigative science can be put at the heart of the curriculum and that it can still generate assessable investigations. Assessment should be formative as well as summative, so that coursework tasks are integrated into schemes of work. Gott and Duggan (2002) suggested that five to ten separate tasks would give a reasonably reliable indication of pupils' skills in carrying out investigations. This can only be achieved if all subject matter is taught via investigation as intended in all versions of the National Curriculum since 1989. When teachers set the questions, pupils lose the real spirit of investigation. When questions that can be investigated arise along the way, pupils can be encouraged to start thinking about how to address these questions, and to start piloting ideas. Toplis and Cleaves (2006) make some logistical suggestions including better use of technician time, developing rather than repeating enquiries across phases, and broadening our ideas about what can be considered

Table 1 Issues in the teaching of scientific enquiry.

Issues	*Suggestions*
1 Timing; separation of enquiry skills from the theoretical	Enquiries should happen throughout the curriculum and pupil and teacher can select the best ones for assessment
2 Teacher-directed investigations	(a) Respond to pupils' questions along the way, by encouraging scientific enquiry, for example investigation of food preservatives (b) Pupils can investigate the same topic at different levels, for example reactions that generate carbon dioxide can be viewed as simple chemical reactions or as contributors to pollution
3 Restricted topics for enquiry	(a) Broaden enquiry types, for example ecological investigations, primary data such as astronomical data from internet sources (b) Develop investigations within and across schools, for example continue topics such as friction from primary science
4 Restricted time	Encourage investigations over extended time scales, for example meteorological data collection
5 Limited/unfamiliar apparatus	(a) Differentiate pupils' skills with apparatus of graded difficulty (b) More use of ICT, for example temperature, light, pH probes (c) Involve science technicians in demonstrating apparatus

as scientific enquiry. Some practical suggestions are offered in Table 1.

The research in this paper supports a less prescriptive assessment policy that relies less on a performance model for assessment and more on teachers' professional judgement and decision-making. Such a policy would improve the scope and variety of investigative work and be in keeping with the recent emphasis on teaching pupils to think about the status of scientific evidence. Opportunities for the critical analysis of data, according to the AQA (2005) specifications, should arise naturally during the GCSE course. Teachers may consider, in the light of the research reported here, that the GCSE programmes started in 2006 are an opportunity for reclaiming investigation for science learning by teaching science through investigation, and not divorced from it, thereby avoiding the confusions and lack of motivation depicted by the pupils in this article.

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