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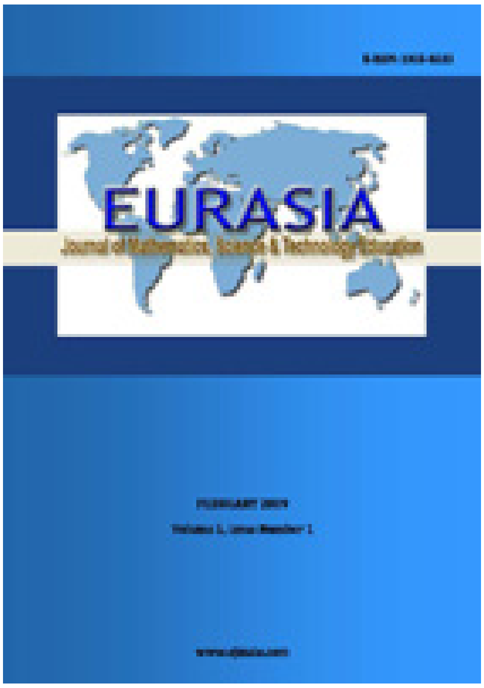


# 'I do and I understand?' Practical work and laboratory use in United Kingdom schools

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# 'I do and I understand?' Practical work and laboratory use in United Kingdom schools

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This paper provides a critical review of the changes to the role of practical work in the science curriculum in England over the last forty years. The science curriculum over this period appears to place an emphasis on an approach to practical enquiry that suggests school students can act like 'real' scientists. This paper provides a critical perspective of this view as it traces the developments of practical work and draws on the literature and on empirical work about how practical science in the secondary school (ages 11 to 18 years) has been enacted over this time period and gives some suggestions about the current situation and how practical work might develop in the future.

*Keywords:* history of science education, practical work, scientific inquiry

## PREAMBLE

'Are we doing a practical today?' is a question often asked by school students as they enter a science classroom in the United Kingdom. Invariably, these rooms are fitted out as working laboratories with the usual array of sinks, water and gas taps, waist high benches and stools. Associated with this traditional layout is a rack or cupboard containing that icon of school practical science; the Bunsen burner. This environment is a common one in UK schools and has been so for several decades. In this paper we take a critical look at how practical work has been carried over the last forty years in the UK, some reasons why it is included in the secondary school science curriculum and what kinds of practical work are experienced. We end with a brief look ahead at the potential future of practical work in schools and at some of the viable alternatives.

### Why do practical work?

There has been a continual debate in the science education literature for at least the last 100 years over the value of engaging pupils in practical, laboratory-type activities (Erickson, 1994, p80).

Practical work is an expensive pursuit for a secondary school in the UK. A lion's share of the cost of running a science department is taken up by replacing/adding to chemical stock, apparatus and related paraphernalia, and if schools ceased the practice of running practical work a consequence would be significant savings of taxpayer's money. Justification for the continuance of practical activities is usually claimed on grounds of enhanced experiences for students in two areas: assisting the learning of science concepts and providing for encounters with the scientific method (Millar, 1991). Lesser-quoted reasons for doing practical work are the provision of positive motivation for learners and the teaching of handling skills. Brief descriptions of these rationales have been offered by writers from the UK and elsewhere, discussed next.

### Motivational reasons

Science students tend to like practicals – as stated at the beginning of this article, teachers are often greeted with 'are we doing practical today, Miss?' Whether this enthusiasm is due to a true affinity towards the empirical collection of data or merely a dislike of the alternative (usually writing) has not been determined. Hodson (1993), while critiquing the effectiveness of practical work, cites motivation as one of the four key

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***State of the literature***

- There is a widely held belief that practical work is a necessary and integral part of science education in schools.
- Students' active engagement with practical work may not automatically lead to learning science concepts.
- That 'working like a scientist' is open to criticism in that different needs, approaches and resources available to professional scientists and to school students are very different.

***Contribution of this paper to the literature***

- This paper provides a critical literature review about the role of practical work in school science.
- It highlights tensions about the use of practical work for teaching, learning and assessment.
- This paper makes an important contribution to the literature in continuing and extending a debate about the role of practical work in school science education.

areas for consideration. Inklings into why practical work is popular in Australia are given by Atkinson (1990) who comments that students have a greater control over the pacing, organisation and selection of the knowledge received, and so can tailor their learning to individual needs.

**Practical work aids learning of theory**

A major aim of secondary school science education in the UK is the presentation of a currently accepted canon of facts and ideas to children, in the hope that they construct meaningful concepts from the experience for use in either further scientific study or everyday life. A good proportion, typically one half to two thirds of their allocated time for science, is spent studying theory without a 'hands-on' component (older studies concur with this view: Thompson, 1975; Beatty & Woolnough, 1982), and practical work is seen as a continuance of this substantive learning, providing for the elucidation, consolidation and discovery of material also covered during 'bookwork'. "At the level of concepts it is necessary to see some experiments, perhaps even to handle them, in order to understand the theoretical ideas involved" (Millar, 1989, p55). "Practical work should be an integral part of the science curriculum which mirrors, reinforces and augments the rest of the course" (Gott & Duggan, 1995, p25).

Atkinson (1990) points out how science educators typically advocate practical work, and states that scientific knowledge cannot be learned effectively from books.

Internationally, this facet of allowing exposure to the authenticity of apparatus and techniques has been echoed by Gunstone (1991, p71) who recognises the value of "…real events". However, these assumptions have been challenged, for instance by Erickson (1994) who asks to what extent practical work increases understanding of scientific knowledge, and exactly how this learning occurs. Watson (2000) comments that pupils do not automatically progress from observing phenomena to constructing concepts.

Watson (ibid.) believes observations alone are not sufficient for learning. They firstly need teacher guidance to help select the relevant features, and secondly require additional experiences such as "…talking or reading about phenomena as well as seeing them" (ibid., p60). Hodson in 1993 commented that the research literature held hardly any evidence to show that practical work is effective in teaching scientific knowledge. Perhaps surprisingly, Thijs and Bosch (1995) concluded the overall effects on learning when teacher demonstrations in the Netherlands were compared to small group practicals did not differ. Roth, McRobbie, Lucas and Boutonne (1997) describe how a teacher who expected Australian students to see particular phenomena during a physics practical activity found they failed to do so, as learners brought their own ideas about motion to the lesson which affected what they observed, resulting in some students leaving the room struggling with their own interpretations.

Conceptual change studies have utilised practical activities during attempts to teach accepted science and rectify misconceptions, with mixed success (Carmichael, Driver, Holding, Phillips, Twigger & Watts, 1990).

**Practical work teaches students to act like real scientists**

"More recently, the skills and processes of science have been treated as a substantive part of the science curriculum with equal status to the traditional 'theoretical' part of the curriculum" (Watson, Swain & McRobbie, 2004, p26). The Nuffield courses of the 1960's, influenced by Piaget, introduced the idea into UK schools that students should be 'scientist for a day', re-enacting experiments and investigations using scientific methods (Fairbrother & Hackling, 1997). This approach has been reworked under various guises since Nuffield's first inception, and can be seen today in the National Curriculum for England and Wales in the form of a 'scientific enquiry' strand, which lists a set of process skills as a hierarchical scale of achievement levels. The benefits of encouraging students to behave as scientists include:

- *Familiarity of 'good practice' in science - what are the acceptable conventions for experimentation (i.e. process concepts) (Millar, 1989).*

- *More control of their experimenting, so imparting a sense of ownership, and promoting motivation (Atkinson, 1990).*
- *Transfer of process skills to other areas of the school curriculum, as well as to everyday problems (Millar, 1989).*
- *An acceleration of general cognitive development (Shayer, 1999).*
- *Teaching of the value of empirical evidence (Gott & Duggan, 1996).*

Despite these benefits, Hodson (1993) provides an accurate reflection when he states scientific values such as being objective, value-free, open-minded and willing to suspend judgement are at odds with covert aims of school science students, such as the need to get the right answer given by the textbook, or what ought to happen.

### Teaching 'practical skills'

There has been a shift in England and Wales since the 1960's away from practical work for teaching apparatus handling skills and towards augmentation of knowledge and understanding of substantive concepts, and 21st century UK school science has little to do with the formal assessment of these skills.

### Practical work in context: a recent UK history

A consideration of the historical influences that determined the introduction of practical work into the English science curriculum and its development is beyond the scope of this article, and has been covered in previous works (Gee & Clackson, 1992; Gott & Duggan, 1996; Simon & Jones, 1992). Focusing on contemporary times, Wellington (1998) has identified three important movements in science education since the 1960's. He terms them the discovery approach, the process approach and (after Jenkins, 1979) 'practical work by order'. To these three movements we could add a fourth and very recent development, that of How Science Works. The Nuffield Projects of the 1960s and 1970s exemplified the discovery approach, based on late nineteenth century ideas of heurism, promoted by Armstrong (Jenkins, 1979), that pupils should discover things for themselves by enabling them to practise scientific methods. These projects had additional advantages of providing a more active approach to learning, of increasing motivation and recall, and of providing an understanding of the nature of inquiry and the nature of science (Wellington, 1981). However, they were open to criticism. For pupils familiar with a body of science knowledge, transmitted by the teacher or textbook, the approach was not always clear. "What's supposed to happen, sir?" (Wellington, 1981, p167) summarises the problem faced by pupils expected to 'discover' knowledge themselves, resulting in contrivances to obtain a 'correct' answer; one that matched the expected scientific outcome. The problems of discovering knowledge in isolation from a knowledge of the science itself, as opposed to interpreting new knowledge with a prior scientific understanding, has been discussed by Driver (1975) who noted that pupils may bring in alternative frameworks consistent with their observations but not with acceptable theory.

The process approach placed emphasis on scientific process skills such as classifying, observing, and inferring, rather than science content such as facts, laws and principles (Gott & Duggan, 1995). Millar & Driver (1987) have discussed some of the problems with a process approach to learning science. They point out that there is not necessarily a dichotomy between process and content but that the two are integral to learning science, adding that learning content is an active process and not mere rote learning and recall of facts. They also note that processes may be generic, for example observation and evaluation, and that they are not unique to science alone. Furthermore, they argue that although scientists may have characteristic ways of working, the "scientific method" cannot be rendered into set of rules for the way that science is carried out (ibid, p41). Indeed, in professional science debate remains as to whether there is a single scientific method that can be generically applied (Lawson, 2010).

### Practical investigative work in the National Curriculum: authentic or contrived?

With the arrival of a National Curriculum for Science in England and Wales in 1989, the practical enquiry section, science attainment target 1 – known commonly as Sc1 – embedded investigative science as a requirement for all state maintained schools in the two countries. This was the first time investigative work in school science was enshrined in a statutory curriculum. Students now had to predict, carry-out, analyse and evaluate investigative science. Although these skills were an integral part of the process of science schemes prior to the National Curriculum, they were neither a requirement nor adopted in every school. The curriculum in the other two countries of the United Kingdom, Scotland and Northern Ireland, remained independent of this National Curriculum and, with its own devolved government, Wales followed its independence from the English curriculum in 2008.

Sc1 has become problematic and open to a degree of criticism, both about its definition and in particular about the way it has been implemented in practice. A brief look at some definitions of the term 'investigations' points to different opinions about its meaning. Woolnough (1994) indicates two kinds of investigation: hypothesis testing to reinforce theoretical understanding, and problem-solving to learn the ways of working as a problem-solving scientist. He suggests that the hypothesis-testing type of investigation is the one found in the National Curriculum (of 1991). Gott and Duggan (1995) recognise the debate about what qualifies as an investigation. They mention the unique status of investigations in science teaching and cite the Assessment of Performance Unit's definition as *a task for which the pupil cannot immediately see an answer or recall a routine method for finding it.* Essentially, this definition is one of problem solving. This appears in other National Curriculum subjects, suggesting that problem solving in science is not unique; that it is a generic approach, a general vocational skill (Coles, 1997). Lock (1990) highlights a problem with definitions:

> *The use of terms like 'open-ended', 'investigations' and 'problem-solving' has become common place in the science education literature, but it seems that wide variations in meaning are attributed to them. In some cases they appear to be used in an interchangeable manner, in others subtle distinctions are made and yet further, conflicting interpretations are applied to a common term (Lock, 1990, p63)*

The National Curriculum Council (NCC, 1993) commented that investigations can stem from pupils' statements and predictions in response to what they have seen, experienced or discussed. They suggest that investigative work: "encourages pupils to raise their own questions, predictions and statements such as, 'I think that … because …', which may then be tested" (NCC, 1993, p19). This then appears to include both the hypothesis testing *and* problem solving types of investigation. In discussing different types of investigation, Wellington (1994) opens up the field by proposing a typology of investigations (p142) that includes a variety of possible questions beginning with 'which', 'what' and 'how do', as well as general investigations that may include survey and project work. The curricula of countries beyond the UK similarly view investigations as not being a homogenous group of pupil tasks, but instead recognise that there are different types. For example, what in the UK are *investigations* are in the US termed *inquiry lessons*, and American science educators have produced typologies with respect to the level of pupil autonomy - Abrams, Southerland and Evans' scheme (2007) has three levels of inquiry, from level 1 (structured inquiry) to level 3 (true open ended tasks).

The investigations carried out as part of Sc1 of the National Curriculum follow a particular model and can therefore be regarded as a subset of all types of investigative work. A further problem with such a variety of possible interpretations of investigative work is that activities chosen may not be investigations as such but versions of illustrative practical work that are little more than recipe following exercises with titles starting with, for example, 'An investigation to show that… '; the term 'investigation' being used in the same way that 'experiment' has been used in the past.

### *How Sc1 has been implemented in practice*

The subsequent interpretation of Sc 1 by classroom practitioners has given rise to a range of criticisms that hinge on the range of practical enquiry activities carried out, when they are carried out, and their purposes. The first criticism is based on the match – or mismatch – between conceptual and procedural knowledge. Watson (2000, p60) notes that, "… progression from observations of phenomena to the construction of scientific concepts is not a simple one". It appears that in practice, conceptual and procedural knowledge development remain somewhat separate where an aim for investigations for many teachers is to develop the procedures of science with teaching for conceptual understanding taking second place (Watson, 2000). This dichotomy has been recognised by the national inspection body, Ofsted, where:

> *The important place of investigation in science has been confirmed by the National Curriculum but much investigatory work remains separate from other activities and is used as a tool for the assessment of practical skills rather than an integral part of teaching (Ofsted, 1999, p3).*

Importantly, Ofsted note the assessment of investigations. This is one area that has drawn major criticisms about the way that investigations are carried out in practice, criticisms that are supported by research.

A major survey backed by the Qualifications and Curriculum Authority (Nott, Peacock, Smith, Wardle, Wellington & Wilson, 1998) reported the opinions of Local Education Authority (LEA) personnel, teachers and pupils about science at ages 11 to 16. Part of this report included data from questionnaires and interviews about practical work and Sc1 investigations. The pupil comments about their experiences of school science in the 14 to 16 age group were retrospective in nature as the pupils were a year older (17 years) when the survey was carried out. The survey revealed that just over half of the pupils felt there was less practical work in the 14 to 16 age group than in earlier years of secondary school science. A majority felt they should be allowed to repeat practicals to improve marks and most felt sure that they knew how to get good marks in Sc1 at GCSE. A clear majority felt that Sc1 work was more about "getting a good mark" than learning or understanding some science (Nott *et al.*, 1998, p30). Pupils realised they had to do practical work in the "correct manner" and several of them complained that practicals were really "pretend", since they knew the answers and had done similar things before (ibid, p33). These responses lend support to the comment:

> *Sc1 investigations are generally routines that teachers know will provide access to all the levels and can be organised and*

*completed quickly in small "windows" of time. (Nott & Wellington, 1999, p17)*

In a study of investigations with the same 14 to 16 age group in Northern Ireland, Jones, Gott and Jarman (2000) interviewed over 100 pupils from 30 different schools at the start and towards the end of the science course. They found that the major responses from pupils about practical work were one of enjoyment, valuing independence as a feature of the activity, appealing to pupils' spirit of enquiry and providing a sense of achievement. Twelve of the pupils however, did not enjoy doing investigations, the reasons cited being shortage of time and the requirement to write and submit a report for GCSE coursework and the attendant exam pressure. Jones *et al.* (2000) also report that some pupils found the experience either too intellectually challenging or insufficiently engaging.

Keiler and Woolnough's (2002) report of research carried out in one school highlighted the following six major categories of motivational behaviours during practical coursework: implementing correct procedures; following instructions; doing what is easy; acting automatically; working within limits; and earning marks. It shows that pupils:

*...were all very clear about the supreme importance of the assessment system in creating and curtailing their choices and behaviours during the two years leading up to the GCSE examinations (Keiler & Woolnough, 2002, p84)*

Research reported by the authors (2006) identified pupils' concerns about the limited time available, when investigations were carried out during the two-year GCSE course, lack of familiarity with apparatus and the association of investigations almost exclusively with assessment. Pupils perceived the teachers' role in investigations as one of trainer and supporter of strategies to maximize performance for assessment. Furthermore, there is a need to fit investigative work and its attendant demands, in terms of apparatus, technician time and resources, into what is often perceived by teachers as an overburdened curriculum (Donnelly, Buchan, Jenkins, Laws & Welford, 1996). To yield good marks within the full range of possible scores, teachers often select certain set-piece investigations as they seem to be sufficiently flexible to allow pupils of different abilities to achieve their potential. The demands made by examination boards to both internally moderate within schools, and to externally moderate between schools, may make tried-and-tested investigations more attractive than new and novel approaches that need to be trialled and accepted. They concluded that the tendency to train pupils to do investigations may be viewed as a response to the 1988 Education Reform Act, where the comparison of school with school, the so-called 'league tables', has given rise to a culture of high stakes assessment that seems to have had the widespread effect of conflating the teaching and assessment of investigations.

Although some students reported in the research clearly enjoy investigative approaches to practical work, time constraints, moderation requirements and the dominance of assessment have resulted in practical investigative coursework being restricted to a few tried and tested investigations, divorced from day-to-day science teaching. This has been reported by no less than the UK House of Commons Science and Technology Committee in 2002 where they stated that:

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, p21).

There are indications of a shift in how and where practical work is used, and a more critical view about how it can be used for student learning. More recent research (Abrahams & Millar, 2008) has addressed the effectiveness of practical work as a teaching and learning method in school science. They report the use of a framework model to analyse specific practical tasks from twenty-five case study lessons using observation and interview data. Their findings from analysis of these data indicate that the teachers' focus on the practical lessons was predominantly one of developing scientific knowledge rather than developing scientific enquiry and that practical work was generally effective at getting pupils to do what was intended with physical objects rather than use scientific ideas and reflect on the data. They note that there was little evidence of a cognitive challenge in linking observables to ideas, and that practical tasks rarely incorporated explicit strategies to help pupils make these links.

A model for assessing the effectiveness of particular practical work activities has been developed further by Millar (2010). This model is based on idea that the fundamental purpose of practical work is to help students link the domain of objects and observables – things they can see and things they can handle – with the domain of ideas – things they cannot observe directly. Different practical activities may utilise the domains to a greater or lesser extents but in a number of activities the understanding of scientific ideas may be important and the thinking behind the doing is an important factor: hands on and minds on. The analysis of effectiveness model relies on learning objectives, the specification of the activity – what students should do, the planned classroom events and the actual learning outcomes.

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