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ANALYSING PRACTICAL SCIENCE ACTIVITIES TO ASSESS AND IMPROVE THEIR EFFECTIVENESS

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Introduction

Practical work is a prominent and distinctive feature of science education. Many science teachers and others see practical work carried out by the students themselves[1] as an essential element of good science teaching. As one teacher put it in an interview study (Donnelly, 1995), 'it's what science is all about really … Science is a practical subject' (p. 97).

Many science teachers believe that student practical work leads to better learning – because we all understand and remember things better if we have done them ourselves. But anyone who has taught science knows from experience that students often do not learn the things we hoped they would learn from a practical activity – and research studies tend to support this view (Millar, 2010). This has led some science educators to question the contribution of practical work to learning. Osborne (1998) argues that practical work 'only has a strictly limited role to play in learning science and that much of it is of little educational value' (p. 156). Hodson (1991) claims that: 'as practised in many countries, it is ill-conceived, confused and unproductive' (p. 176). Perhaps a key phrase here is 'as practised'. Is the kind of practical work we use, and the way we use it, effective in developing students' knowledge, understanding and skills?

It does not seem sensible to ask this question about practical work in general. Practical activities differ considerably in what they ask students to do and what they are trying to teach. If we are interested in the effectiveness of practical work, we really have to consider specific practical activities that we use, or plan to use. The main purpose of this booklet is to provide a tool for doing this in a systematic way – for analysing any given practical activity to clarify its objectives, highlight its main features, and evaluate its effectiveness. Before embarking on this, however, it is useful to explore a littler further what we mean by 'effectiveness'.

[1]Another form of practical work is demonstrations carried out by the teacher with the students observing and perhaps assisting. The focus in this booklet, however, is on practical work carried out by the students.

Analysing practical activities

The previous section made three key points.

- Practical activities are very diverse, so we should consider the effectiveness of practical activities individually, rather than of practical work in general.
- The starting point in considering any practical activity is its learning objective(s).
- The way a practical activity is designed and presented may have a significant influence on the extent to which its learning objective(s) is/are attained.

This section will present and explain an instrument (a checklist) for analysing practical activities to provide a clear description of their principal features. This then provides a basis for considering the effectiveness of a practical activity, and for thinking about how it might be modified to improve its effectiveness. The components of the checklist are shown in Table 2.

Table 2 Components of the practical activity analysis checklist

1	**Learning objective (intended learning outcome)**	
	- Developing knowledge and understanding of the natural world	
	- Using scientific equipment or following standard procedures	
	- Developing understanding of the scientific approach to enquiry	
2	**Design**	
	2.1	Degree of direction given
	2.2	Logical structure
	2.3	Importance of scientific ideas
	2.4	What students have to do with objects and materials
	2.5	What students have to 'do' with ideas
3	**Presentation**	
	3.1	Students' awareness of purpose of activity
	3.2	Explanation of task to students
	3.3	Nature of discussion before activity
	3.4	Nature of discussion after activity
	3.5	Students' record of the activity

The complete checklist is shown in Appendix 1. The rest of this booklet discusses each of its components in turn, with the aim of clarifying the coding categories suggested and explaining some of the reasons behind them.

Learning objective (or intended learning outcome)

As regards their learning objective(s), practical activities can be divided into three broad groups that help students:

A develop their knowledge and understanding of the natural world
B learn how use a piece of scientific equipment or follow a standard practical procedure
C develop their understanding of the scientific approach to enquiry

We can then subdivide each of these further, to identify the learning objective(s) more precisely.

Figure 3 suggests a way of doing this. To complete the tables in Figure 3, you first tick one of the three boxes in column 2, to identify the main objective in general terms (A, B or C above). Then you tick one box in the right-hand column to indicate more specifically what students are expected to learn from the activity. If you choose general objective C, and tick the lower box in the right-hand column, you can then provide more detail by ticking the boxes that apply in the table at the bottom of Figure 3.

Of course, some practical activities may appear to have objectives in more than one of the groups A, B and C above. But often one of these is the principal objective – and it can be useful to recognise this. But if you genuinely believe that there are important objectives in more than one of the main groups, an alternative way of using Figure 3 is to enter numbers 1, 2 (and if absolutely essential 3) in the second column, to indicate the priority order of main objectives – and then to tick more than one box in the right-hand column to indicate the specific objective in each of the main groups you have indicated.

Figure 3
Identifying the learning objective (or objectives) of a practical activity

Objective (in general terms)	Tick ✔ **one** box to indicate the main objective	**Learning objective (more specifically)**	Tick ✔ **one** box
A By doing this activity, students should develop their knowledge and understanding of the natural world		Students can recall an observable feature of an object, or material, or event	
		Students can recall a 'pattern' in observations (e.g. a similarity, difference, trend, relationship)	
		Students can demonstrate understanding of a scientific idea, or concept, or explanation, or model, or theory	
B By doing this activity, students should learn how to use a piece of laboratory equipment or follow a standard practical procedure		Students can use a piece of equipment, or follow a practical procedure, that they have not previously met	
		Students are better at using a piece of equipment, or following a practical procedure, that they have previously met	
C By doing this activity, students should develop their understanding of the scientific approach to enquiry		Students have a better *general understanding* of scientific enquiry	
		Students have a better *understanding of some specific aspects* of scientific enquiry	

If you have ticked this box, please complete the table below

Specific aspects of scientific enquiry	Tick ✔ **all** that apply
How to identify a good investigation question	
How to plan a strategy for collecting data to address a question	
How to choose equipment for an investigation	
How to present data clearly	
How to analyse data to reveal or display patterns	
How to draw and present conclusions based on evidence	
How to assess how confident you can be that a conclusion is correct	

The categories in Figure 3 are influenced by research. Many studies suggest that practical activities whose main aim is A (to help students develop their knowledge and understanding of the natural world) vary considerably in learning demand. If the objective is for students to observe an object, or material, or event that they have not seen before, or not looked at closely before – and to remember what they see – then the learning demand is relatively low. Many students will recall it for some time; the more surprising or striking the observation is, the longer they are likely to remember it. But if the objective is to help students develop their understanding of explanatory ideas, concepts, models or theories, then the learning demand is much greater. Much practical work is relatively ineffective because teachers underestimate the challenge the students face in making sense of what they see. The idea that explanations 'emerge' from observations has been called 'the fallacy of induction' (Driver, 1983). We might expect that activities of high learning demand would be designed or presented in class in ways that reflected this; a recent study, however, found little difference in the way activities of higher and lower learning demand were designed or presented (Abrahams and Millar, 2008).

The way teachers use practical activities whose main aim is C (to help students develop their understanding of scientific enquiry) often seems to imply a belief that 'practice makes perfect' – that students will get better at planning and conducting their own investigations simply through practice. Research, however, tends to suggest that more effective learning occurs when specific aspects of scientific enquiry are identified and taught (Watson, Wood-Robinson, and Nicolaou, 2006; Millar, in press). So the coding scheme in Figure 3 for type C activities aims to encourage you to think in more detail about *exactly* what you want your students to learn from any practical activity of this sort that you use. Some activities with more specific and targeted learning objectives might be more effective – and may help students develop knowledge that they could then apply in other investigative work.

Design of practical activities

Open or closed: Degree of direction given

A frequent criticism of practical work in school science is over-reliance on 'cookbook' or 'recipe following' tasks – where students are given detailed instructions on what to do, often in the form of a worksheet. Students, when doing such activities, often lose sight of the overall purpose of the activity and follow the instructions rather mechanically and without much thought.

To think about this, you might ask, for a given practical activity, how each of the following aspects of the activity is decided upon:

- the question to be addressed
- the equipment to be used
- the procedure to be followed
- the methods of handling data collected
- the interpretation of results

Is it determined completely by the teacher, perhaps via a written worksheet or detailed oral instructions? Or is it, at the other extreme, left entirely open to the students to decide? Or is it somewhere in the middle, perhaps decided after some whole-class discussion about ideas and options, or where the teacher provides a general framework but leaves some choices open to the students? Table 3 can be used to indicate how open or closed the activity is.

Degree of direction given (how open/closed?)	Tick ✔ **one** box
Question given, and detailed instructions on procedure	
Question given, and outline guidance on procedure; some choices left to students	
Question given, but students choose how to proceed	
Students decide the question and how to proceed	

Table 3 Degree of direction given (how open/closed?)

Logical structure

Another important aspect of a practical activity is the extent to which it is 'data driven' or 'ideas driven'. Does the activity begin by collecting data in the form of observations and measurements 'to see what happens'? Or does it start from thinking about a situation or question, perhaps saying what we might expect, and then collecting data to see if this is correct or has to be modified? Tasks with this second kind of logical structure are more likely to integrate thinking and doing. Also, as discussed earlier, there is a risk that activities that begin from data may be based on