Getting Practical

Practical work: making it more effective

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ABSTRACT This article outlines a model for thinking about the effectiveness of practical activities in school science and how this might be evaluated. This was used in a research study of current practice in the use of whole-class practical work in secondary schools in England. The emphasis in the lessons observed was on successfully 'producing the phenomenon'. Little whole-class time was used to discuss the ideas that the activity involved. Task design did not reflect the wide variation in task demand. This suggests a need for greater clarity about the learning objectives of practical activities, and wider use of strategies to increase the 'minds on' aspects of practical work.

Practical work is an essential part of science education. In science lessons, we are trying to extend students' knowledge of the natural world and develop their understanding of the ideas, theories and models that scientists have found useful in explaining and predicting its behaviour. Teaching science naturally involves 'showing' learners things, or putting them into situations where they can see them for themselves.

In this article, our focus is on whole-class practical activities carried out by the students themselves, usually in small groups. Most science teachers see practical work of this sort as an essential feature of their everyday work. Many say that they believe it leads to better learning: we are more likely to understand and remember things we have done than things we have just been told. And we know, both from experience and research, that students like practical work, preferring it to other kinds of lesson activities. On the other hand, we also know from experience that students often do not learn from a practical task the things we wanted them to learn. A few weeks after carrying out a practical task, most recall only specific surface details of the task and many are unable to say what they learned from it, or what (as regards science learning) they were doing it *for*.

This has led some science educators to question the contribution of practical work to learning. Osborne (1998) suggests 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. For many children, what goes on in the laboratory contributes little to their learning of science*' (p. 176). Others have voiced similar doubts. Perhaps a key phrase in Hodson's comment is '*as practised*'. Practical work is essential in science teaching and learning, given the subject matter. But do we use practical work effectively? To answer that question, we need first to ask ourselves what we mean by 'effectiveness'.

What do we mean by 'effectiveness'?

To think about the 'effectiveness' of a teaching/learning activity of any kind, it is useful to consider the steps in developing such an activity, and in monitoring what happens when it is used. The model shown in Figure 1 was originally developed by the European Labwork in Science Education project (Millar, Tiberghien and Le Maréchal, 2002).

The starting point is the learning objectives that the teacher (or whoever developed the activity) had in mind (box A in Figure 1). These will, of course, be influenced by a number of things: the context in which the activity will be used (what the curriculum being followed requires, what resources are available, how the students will be assessed, etc.); their views of science (what they think it is important to teach); and their views of learning (what they think is appropriate

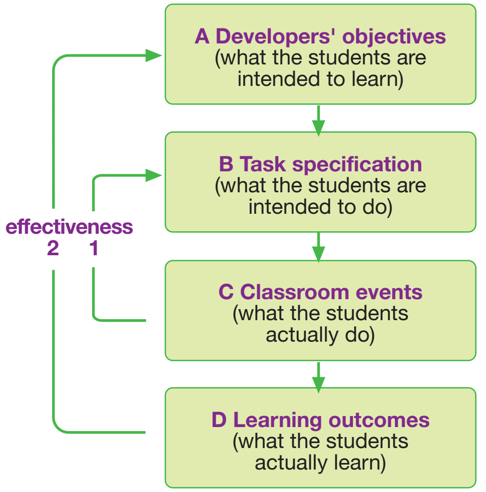

Figure 1 Stages in the development and evaluation of a teaching and learning activity – and their relationship to two senses of 'effectiveness'

for learners of the age and stage for which the activity is intended). The learning objectives are a statement of what the students are intended to learn from the activity. In practice they may be stated explicitly, but are often somewhat implicit.

These intentions are then translated into an activity or task: a statement of what the students are to *do* in order to achieve this learning (box B). This might be specified in great detail or in more general terms. The design of the activity is influenced by the same considerations as the learning objectives.

When the activity is then implemented in practice, we can observe the classroom events that occur – we can see what the students actually do during the activity (box C). This again will be influenced by several factors: the students' understanding of science (what they know about the topic in which the activity is set; how competent they are in using the equipment involved, etc.); the context of the activity (what their curriculum requires, how they will be assessed, etc.); and their views of learning (for example, whether they really think that learning is about constructing meaning from experience, or see it as a matter of being 'given' ideas and insights by a teacher). As a result, the actions of the students may be close to what the designer of the activity had in mind, or may differ from it to a greater or lesser extent. It may become very clear when we observe an activity in use that its design needs to be improved in order for the students to do what we intended and see what we meant them to see. This is the first, and most basic, sense of effectiveness: the match between what we intended students to do and see and what they actually do and see. This is about the relationship between box C and box B in Figure 1. In Figure 1 we have labelled this 'effectiveness 1'.

Often, however, when people talk about the effectiveness of a teaching activity they mean the extent to which it helped students to learn what we wanted them to learn. This is about the relationship between box D and box A in Figure 1. We call this 'effectiveness 2'. It is not, of course, easy to assess or measure. We would first need to decide if we were interested in evidence of learning in the short term or in the medium and long term. And we should recognise that learning, when it does occur, is likely to be the result of a sequence of lesson activities of which a practical activity is just a part.

A range of objectives

Thinking about effectiveness of practical work begins from the learning objectives of activities (box A in Figure 1). Practical work in school science clearly has a range of learning objectives. Practical activities might be classified according to their learning objectives into the three types shown in Table 1.

Some practical activities may, of course, have several objectives, which could fall into more than one of the categories in Table 1. In the case of practical activities which aim to help students develop their knowledge and understanding of the natural world (**type A: illustrating ideas**), there is another important distinction to be made before we can consider their effectiveness. This stems from a point made by several science educators (for example, Tiberghien, 2000), that the fundamental purpose of much practical work in science is to help students to make connections, or links, between two domains: the domain of objects and observables (things or properties that we can see directly) and the domain of ideas (often involving unobservable entities and behaviours) (Figure 2).

Practical activities differ considerably in the extent to which both domains are involved and important. For some activities, the aim is that students should observe an object, a material or

Table 1 Classifying practical activities by their main learning objective(s)

Type	The main objective of the practical activity is:
A	to help students develop their knowledge of the natural world and their understanding of some of the main ideas, theories and models that science uses to explain it
B	to help students learn how to use some piece(s) of scientific apparatus and/or to follow some standard scientific procedure(s)
C	to develop students' understanding of the scientific approach to enquiry (e.g. of how to design an investigation, assess and evaluate the data, process the data to draw conclusions, evaluate the confidence with which these can be asserted)

an event, and remember some things about it. For other activities, the aim is to help students understand some of the ideas that science uses to describe or to explain what they observe – and these only really make sense as activities if you look at them from the perspective (or 'through the spectacles') of a particular set of ideas. For such activities, thinking is as important as doing. They can only work if students are both 'hands on' and 'minds on'. To assess the effectiveness of such activities, we really have to take account of both domains of Figure 2. In the language of the model in Figure 1, we need to look at what students 'do' with ideas, as well as what they do with objects and materials on the laboratory bench (box C); and we need to look at how well the activity supports their learning of ideas and not merely their recollection of observable events (box D). The implications of this are set out more explicitly in Table 2, which identifies the evidence that would indicate that a practical activity was effective in each of the senses outlined above, in each of the two domains.

In the rest of this article, we will summarise some findings from a study of current practice in the use of practical work, which used the ideas above to consider the effectiveness of practical activities.

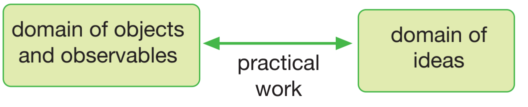

Figure 2 Practical work: helping students to make links between two domains

Practical work in practice

To study practical work in secondary school science, we approached eight schools, asking for permission to observe one or more science lessons at key stage 3 (11–14s) or 4 (14–16s) that included practical work, to talk to the teacher before and after the lesson and, if possible, also to some of the students after the lesson. All the schools approached were Local Authority maintained comprehensive schools in England. On the basis of their students' performance in national tests and external examinations, they were representative of such schools more generally. Selection of schools for this study is discussed more fully in Abrahams (2005).

We observed 25 science lessons. We had limited control of the content or subject matter of these lessons. Typically, a date was agreed for the observation visit, and several lessons with different teachers were offered as possibles when

Table 2 Clarifying the meaning of 'effectiveness'

A practical activity is:	in the domain of objects and observables (o)	in the domain of ideas (i)
effective in sense 1	Students do what was intended with the objects and materials provided, and observe what they were meant to observe	During the activity, students think about what they are doing and observing, using the ideas intended, or implicit in the activity
effective in sense 2	Students can later recall and describe what they did in the activity and what they observed	Students can later discuss the activity using the ideas it was aiming to develop, or which were implicit in it (and can perhaps show understanding of these ideas in other contexts)

the researcher arrived. Choices were made on the basis of practical considerations of timing, to allow pre- and post-lesson teacher interviews, and with the aim, as the study proceeded, of achieving a spread across the five school years in key stages 3 and 4, and across biology, chemistry and physics topics. The distribution of the lessons observed across key stages and science subjects is shown in Table 3. The lower number of biology lessons may reflect the frequency of practical activities in biology lessons relative to chemistry and physics lessons. The lesson observations later in the sequence seemed to raise the same issues as earlier ones, suggesting that data saturation had been achieved by this point. The content of the 25 lessons observed is summarised in Table 4.

We asked that the lessons observed should not be ones in which students were being assessed – and think that schools would anyhow have been unlikely to want additional observers in such situations. Even so, it is worth noting that of the 25 lessons observed, 21 were of **type A: illustrating ideas** (Table 1) and four of **type B: practising procedures**. None was of **type C: enquiry processes**, reinforcing the view that investigative work is used almost entirely for assessment purposes rather than to develop understanding of experimental design or evaluation of evidence (Donnelly *et al.*, 1996). In all 25 lessons, the teacher's focus appeared to be firmly (indeed almost exclusively) on the substantive science content of the practical task, or the practical procedure being taught. There was almost no discussion in any lesson of general points about scientific enquiry, and no examples of the teacher using students' data to draw out general points about the design of experiments, or the analysis and interpretation of empirical data. In some lessons there were clear opportunities to do this, but they were not exploited. As a result, our analysis of these lessons focuses on the use of practical work to develop students' scientific knowledge and understanding – not because we had asked to observe only lessons of this sort, but because this was overwhelmingly the dominant emphasis in the lessons we actually observed.

The approach we adopted in this study was to observe a single lesson and conduct interviews immediately before and after it. The practical difficulties of arranging subsequent visits to attempt to assess student learning, added to the fact that each lesson had different learning objectives that would have been difficult to assess in comparable ways, ruled this out. As a result, we collected more evidence of the effectiveness of activities in sense 1 than in sense 2 (of the model in Figure 1). However, effectiveness in sense 1 is a necessary, even though it is not a sufficient, condition for effectiveness in sense 2.

In general, the practical activities we observed appeared to be much more effective in the domain of objects and observables, than in the domain of ideas. In our view, all the tasks in Table 4 involve elements of both domains, in that they bring in scientific ideas as well as observable features, and a majority of them depended strongly on making connections between the two domains. Most were tightly constrained, of the kind that have been termed 'cookbook' or 'recipe following' practical tasks (Clackson and Wright, 1992). In nine lessons, a printed worksheet was used; in others teachers gave detailed instructions orally, or on the board or overhead projector. Often the teacher demonstrated how to set up equipment in advance, sometimes taking longer than the student practical activity itself. On several occasions the teacher repeated the practical task as a demonstration after the students had done it themselves in groups. Practical activities were judged 'successful' by teachers when students managed to 'produce the phenomenon' and make the intended observations. Teachers seemed clearly concerned about the effectiveness of practical activities in sense 1:o (Table 2) – that a practical activity should enable students to see what they were meant to see.

There was very little teacher talk to the whole class about ideas. Table 4 shows how lesson time was used in the lessons observed. Only in task 25

Table 3 Sample of lessons observed by science subject and key stage

Key stage (and student age)	Number of lessons observed			
	Biology	Chemistry	Physics	Total
Key stage 3 (11–14)	2	6	7	15
Key stage 4 (14–16)	1	3	6	10

did the teacher use a significant amount of time in discussing ideas and models that were useful for interpreting observations. For other tasks it is, of course, possible that some discussion of this sort may have taken place in a previous lesson, or will take place in a subsequent one. Even so, the imbalance in the time allocated to ideas compared to that allocated to objects and observables suggests a strong focus on the 'hands on' aspects of tasks at the expense of the 'minds on' aspects.

It was also striking that there were no obvious differences between the presentation of tasks which strongly depended on the domain of ideas and tasks which were largely located in the domain of observables. This might suggest that teachers (and the authors of practical tasks) are unaware of the significantly greater cognitive demand of tasks that strongly involve the domain of ideas. Our sense in several lessons observed was that the teacher implicitly held an empiricist view of knowledge – that explanatory ideas 'emerge' or 'become evident' from the data itself. This seriously underestimates the role of current conceptual frameworks in channelling thinking, and the imaginative effort involved in generating plausible explanatory models (Driver, 1983).

The account above is a very brief overview of the main findings of this research study. For a fuller account, see Abrahams (2005) and Abrahams and Millar (2008).

Table 4 Practical activities observed and allocation of time to different aspects of the activity

Task	Content	Key stage	Time (in minutes) spent		
			by teacher on whole class discussion of		by students on
			what to do with objects/ materials	ideas and/or models to be used	manipulating objects/ materials
1	Food tests: test results	3	13	0	28
2	Heart beat/pulse: numerical equivalence	3	13	0	10
3	Chemical reactions: how to identify	3	4	0	46
4	Separation: sand and pepper	3	11	0	20
5	Separation: iron, salt and sand	3	17	3	14
6	Chromatography: separation of inks	3	3	0	30
7	Cooling curve: characteristic plateau	3	15	0	40
8	Chromatography: separation of inks	3	14	0	18
9	Heat absorption: colour as a variable	3	9	0	28
10	Electric circuits: current conservation	3	8	0	23
11	Electric circuits: current conservation	3	10	0	28
12	Electromagnets: factors affecting strength	3	14	0	26
13	Electromagnets: factors affecting strength	3	6	0	34
14	Pulleys and levers: factors affecting	3	9	4	25
15	Magnetic permeability of materials	3	10	0	20
16	Starch production: factors that effect	4	21	0	33
17	Acid + base = salt + water	4	11	0	40
18	Electrolysis: increase in cathode mass	4	9	5	33
19	Electrolysis: cathode deposits	4	14	0	23
20	Lenses and eyes: similarities	4	2	0	7
21	Refraction: ray paths	4	33	0	10
22	Current in series and parallel circuits	4	10	0	24
23	Voltage in parallel circuits	4	5	0	34
24	Work done in raising mass	4	11	5	15
25	Current and voltage in series circuit	4	7	29	14

Improving practice

The findings of this study draw attention to some characteristics of current practice in the use of practical work in secondary science teaching. They suggest that we need to increase the 'minds on' aspects of practical work, if we want to make it more effective in developing students' understanding of scientific ideas. The framework we used to analyse lessons may also be a useful tool for teachers to reflect on the practical work they currently use, and to think in a more detailed way about its effectiveness.

For practical work to become more effective, we first need to be more clear and precise about the purposes of each practical activity. Using a practical activity is a choice – a decision about which method is likely to be best for achieving a specific learning objective (or objectives). For practical work of the type we have termed **type A: illustrating ideas** (Table 1), it is important to consider the learning demand of the activity (Leach and Scott, 1995). Tasks that strongly involve the domain of ideas are likely to have significantly higher demand than those which simply aim to allow students to see, and remember, an observable event. In such tasks students are likely to require assistance to use or develop the ideas that make sense of the activity and lead to learning. Tasks that have this kind of 'scaffolding' built into their design are likely to be more effective.

Practical work will always have a key role in science teaching. The challenge is to find ways to make it a great deal more effective as a teaching and learning strategy than it often is at present. In our view, these centre around clear identification of learning objectives, informed analysis of the learning demand of tasks, and the design and presentation of tasks to assist students in thinking about their actions and their data in the way we intend. Improvement is not a matter of doing more practical work, but of doing better practical work.

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