# Practical Work in Science Education: Recent Research Studies

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# 'Mapping' the domain

## Varieties of practical work

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*Practical work occupies a central place in science education in many countries. Practical work in science, however, is very varied in type, and in intention. If we, as teachers and researchers, want to explore the effectiveness of practical work in achieving educational goals, then we need to be clear about the different types of practical work which are (or could be) undertaken in classes, and their different purposes and characteristics.*

*In this paper, a typology of practical work (a 'map') is presented, and some of its implications for teaching and research will be explored. A 'map' of this sort may help us see how to address the key question of the effectiveness of practical work.*

## 1 Introduction

The subject matter of science is the natural world around us, what it contains, how it works, and how we can explain and perhaps predict its behaviour. So it is hardly surprising that, in teaching science, we often find that we want to allow students to observe, handle and manipulate objects and materials for themselves, rather than simply talking about them, or showing representations of them (such as diagrams, photographs, or video extracts). Not only does practical work with real objects and materials help us to communicate information and ideas about the natural world, it also provides opportunities to develop students' understanding of the scientific approach to enquiry. Furthermore, practical work is the aspect of science education which students say they most enjoy. For all these reasons, most science educators would agree that science courses at school and university levels should contain significant amounts of practical work.

Practical work carried out by the students themselves, usually working in small groups, is a prominent feature of school science education in many countries. In other countries where there has not been such a strong tradition of student practical work, introducing it, or increasing the amount of it, is often seen as a desirable reform, and as a means of improving science education. This enthusiasm for practical work in science education persists despite the fact that it makes science a relatively expensive subject on the school curriculum. Laboratories are more expensive to build and maintain than ordinary classrooms; practical work requires equipment, and materials which are used up in the teaching activities and have to be replaced.

In countries where there is an established tradition of student practical work in school science, however, its effectiveness is being increasingly questioned. Students often fail to learn from practical work the things we had intended them to learn. Frequently it is carried out very rapidly, or with unreliable equipment, or with insufficient attention to care and precision, so that students fail even to produce the phenomenon they are supposed to observe, let alone be helped to appreciate patterns, trends or explanations. Even when the outcomes are as the teacher intended, conclusions which seem 'obvious' to the teacher can appear less so to the student. Often the work is humdrum and routine, rather than engaging or inspiring. In one recent critique of laboratory practical work, Hodson (1991) argues that:

> As practised in many schools, it [practical work] is ill-conceived, confused and unproductive. For many children, what goes on in the laboratory contributes little to their learning of science or to their learning about science and its methods. Nor does it engage them in doing science in any meaningful sense. At the root of the problem is the unthinking use of laboratory work. (p. 176)

The issue, then, is not about the usefulness, or otherwise, of practical work in general. For the reasons outlined in the opening paragraph, practical work is likely to remain a prominent part of science education. Instead we need to ask about the effectiveness of *specific* pieces of practical work for achieving *specific* learning outcomes. The aim of the work presented in this article was to develop a framework which can help us to raise such questions and, in time perhaps, to answer some of them.

This framework consists of a 'map' – or classification system – which allows us to describe in detail the characteristics of any given piece of practical work. The 'map' of practical work described in this article is a slightly modified version of a 'map of labwork' which was developed by the authors as a general framework for use in the European project *Improving Labwork in Science Education* (LSE) (Millar, Le Marechal and Tiberghien, 1998).



Although a number of classification schemes have been published in the science education literature for analysing types of interaction in the science teaching laboratory (Eggleston, Galton and Jones, 1975; Shymansky et al., 1976; Penick et al., 1976; Hacker, 1984; Hegarty-Hazel, 1990; Giddings, Hofstein and Lunetta, 1991), there have been very few attempts to develop a classification system for science laboratory tasks themselves. Some categories, of course, are well established, such as teacher demonstration and student practical work. The idea of 'levels of enquiry', to describe whether the problem, the procedure and the conclusion are open or given (Herron, 1971), has become widely used. Woolnough and Allsop (1985) propose a general classification of practical tasks into four groups: exercises, experiences, investigations, and illustrations of theory. Kirschner and Meester (1988) suggest a four way classification of laboratory approaches: formal (to illustrate laws and concepts), experimental (open-ended), divergent (from a common start), and skills/procedures related. More detailed classification schemes have also been proposed. Lunetta and Tamir (1981) used a modified version of an earlier scheme by Fuhrman et al. (1978) to compare laboratory tasks in the *PSSC Physics* course and the *Project Physics Course*. More recently McComas (1997) has proposed a taxonomy of 'physical factors' (aspects of the laboratory, the curriculum) and 'personal factors' (characteristics of students and teachers).

Any classification system is designed for a particular purpose and builds in, to some extent, the perspectives of its constructors. In our view, the core purpose of practical activity in science teaching is to help the student make links between the domain of objects and observable things, and the domain of ideas. So we wanted to develop a classification system for practical tasks which would focus more prominently on the kinds of physical actions and operations required of the student in dealing with objects and observables on the one hand, and the kinds of mental actions and operations required of the student in dealing with ideas on the other. The overall purpose is to develop a tool which can be used to provide the kind of information which may be useful for thinking about how to modify and improve practical tasks.

In the LSE project, labwork was defined in a way, which included some activities that might not normally be regarded as practical work, and the focus was on teaching at upper secondary school and university level. In this chapter we have modified some categories and added some new ones to make the map better suited to classifying the kinds of practical tasks used at primary and secondary school level.

## 2 The domain of practical work

It may be useful to begin by making clearer exactly what we will include within the category of 'practical work'. We might define practical work as:

> all those teaching and learning activities in science which involve students at some point in handling or observing the objects or materials they are studying.

This places no restrictions on where the work is carried out. Practical work might be carried out in a laboratory, or outside 'in the field', or in an ordinary classroom. By including the words 'at some point' in the definition above, we emphasise that practical work involves conceptual activity as well as practical activity, so that observing or handling objects and materials is just one element of a practical task. The definition above would also include teaching and learning activities in which the students watch someone else (often the teacher) handle objects or materials, as well as those in which they handle them for themselves, i.e. it includes teacher demonstrations as well as pupil practical work.

We might also want to extend this definition to include activities in which students worked with representations of real objects or materials, such computer simulations, or video recordings of events which would be too dangerous, or too expensive, or too difficult to work with 'for real'. Our definition of practical work would then be enlarged to:

> all those kinds of learning activities in science which involve students at some point in handling or observing real objects or materials (or direct representations of these, in a simulation or video-recording).

There are, however, many ways of classifying any large collection of items – and the merits of any particular classification system depend on the purpose for which it was developed. Our aim, as we have said above, is to provide a framework for asking more precise and specific questions about the effectiveness of practical work. So we will now go on to look a little more closely at what we might mean by 'effectiveness' in this context.



## 3 The effectiveness of a practical task

To help us clarify what we mean by the 'effectiveness' of a practical task in a teaching and learning situation, it is useful to consider the processes involved in designing and evaluating a practical task. A possible model of the logical steps in this process, and some of the influences on them, is shown in Figure 1.

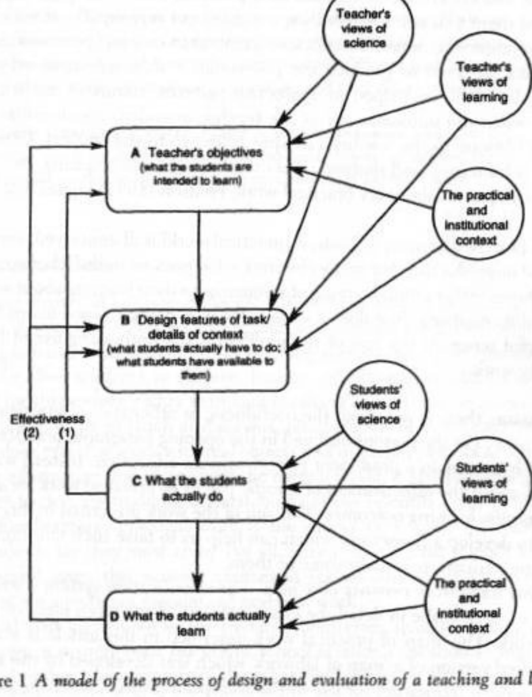


Figure 1 *A model of the process of design and evaluation of a teaching and learning task*

The starting point is Box A: the learning objectives the teacher has in mind. What does he or she want the students to learn? This then leads on to the design of the practical task which is to be used to achieve those objectives (Box B). The choice of learning objectives and the decisions taken about the design of the task (Boxes A and B) are influenced by many considerations. Three of these are shown: the teacher's view of science (ideas about what is important to try to teach, about the nature of this knowledge, and so on); the teacher's view of learning (ideas about how students learn); and the practical and institutional context (the facilities, resources and time available, the way in which students will be assessed, and so on). Some aspects of this background influence may be explicitly acknowledged in selecting the objectives and designing the task, whilst others may be tacit influences.

In designing a practical task, the teacher intends that the students will *do* something when given the task. So the model in Figure 1 leads on to the question of what the students *actually* do when carrying out the task (Box C). The students may do what the teacher intended, or something which differs from it to a greater or lesser extent. For example, students may misunderstand the instructions and carry out actions which are not the ones the teacher intended. Or they may carry out the intended operations on objects and materials, but not engage in the kind of thinking about these which the teacher intended. Finally, we move on to box D: what do the students actually learn from carrying out the task? Like the teacher's decisions in planning the task, the students' actions and learning as they carry it out (Boxes C and D) are also influenced by many factors, three of which are their views of science (their interest in the subject matter, their understanding of the connections to other ideas, and so on), their views of learning (ideas about how one learns the sorts of ideas involved), and the practical and institutional context of the task (the quality of the equipment, the time available, the importance of the task in relation to achieving success in the course, and so on).

This model (Figure 1) now allows us to say more precisely what we mean when we ask: how effective is a particular practical task? We can distinguish two separate questions. First, do the students actually do the things we wished them to do when we designed the task? This is about the relationship between Boxes C and B. We refer to this as 'Effectiveness (1)'. This then leads on to the question of the effectiveness of a task in promoting student learning (the relationship between D and A). This we call 'Effectiveness (2)'.

If we collect some evidence which suggests that a practical task is not very effective, in terms of either Effectiveness (1) or Effectiveness (2), then we might want to re-design the task, whilst keeping the learning objectives the same – or we might feel that we need also to reconsider our objectives, perhaps to make these clearer or less ambitious.



In order to do this, however, we need to have a clear idea about two things:

- the intended learning outcomes, or learning objectives, of the task
- the range of possible variation in the design of the task and the context within which it is carried out.

This allows us to characterise the task we are considering, and may suggest ways in which its objectives or design could be altered. The 'map' which we will describe in the next section provides a means of doing this.

## 4 A 'map' of practical work

The model set out in Figure 1 identifies the two major dimensions of a 'map', or classification system, for practical tasks. The first is the intended learning outcome, or learning objective, of the task. Here we want to classify tasks according to their main learning objective(s). The second dimension is the task design itself. This is more complex and can be sub-divided into a number of sub-dimensions. Any given task can be assigned to one (or more) coding categories within each of these sub-dimensions. The structure of our 'map' is shown in outline in Figure 2.

Many of these dimensions and sub-dimensions are self-explanatory. B1.1 to B1.3, however, may need some explanation. The idea which underlies these is that the fundamental purpose of practical work is to help students to *build bridges between two distinct domains*: the domain of real objects and observable things, and the domain of ideas (Figure 3).

So, in any practical task, students are expected to do certain kinds of things with objects and observables; and they are also expected to do certain things with ideas. Sub-dimensions B1.1 and B1.2 refer to these two aspects of the practical task, whilst sub-dimension B1.3 asks: does the work on objects lead towards the work on ideas (in an inductive manner), or do the ideas come first and lead to the work on objects (perhaps in a more hypothetico-deductive manner)?

| | |
|---|---|
| A | *Intended learning outcome (learning objective)* |
| B1 | *Design features of the task* |
| B1.1 | What students are intended to do with objects and observables |
| B1.2 | What students are intended to do with ideas |
| B1.3 | Whether the task is objects- or ideas-driven |
| B1.4 | The degree of openness/closure of the task |
| B1.5 | The nature of student involvement in the task |
| B2 | *Practical context of the task* |
| B2.1 | The duration of the task |
| B2.2 | The people with whom the student interacts whilst carrying out the task |
| B2.3 | Information given to the student on the task |
| B2.4 | The type of apparatus involved |
| B3 | *Student's record of work on the task* |
| B3.1 | Nature of record |
| B3.2 | Purpose of record |
| B3.3 | Audience for record |

Figure 2 *Main dimensions and sub-dimensions of a 'map' of practical work tasks*

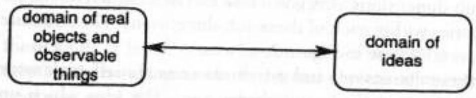


Figure 3 *Labwork: helping students to make links between two domains*

For each sub-dimension, we can then characterise a practical task either by selecting the most appropriate descriptor (or descriptors) from a list, or by ticking the appropriate boxes in a table. The coding categories within each sub-dimension are not mutually exclusive; many practical tasks will have elements which match several of the coding categories. Our aim is not to provide a set of 'pigeon-holes' for each sub-category, so that every task can fit neatly into one of them. Rather it is to provide a means of obtaining a characteristic 'profile' of each practical task.



## 5 Coding categories for each sub-dimension

We will now discuss the coding categories we propose within each sub-dimension, providing examples in some sub-dimensions where this will help to clarify the meaning of the coding categories.

### 5.1 Dimension A: Intended learning outcome (learning objective)

A first dimension to consider in classifying a practical task is the intended learning outcome (or learning objective) which the teacher or the designer of the task has in mind in presenting the task. Learning objectives fall into two main categories, associated with the learning of science content or of the processes of scientific enquiry. These can be further sub-divided as shown in Table 1.

Content:

| | |
|---|---|
| a to help students identify objects and phenomena and become familiar with them | |
| b to help students learn a fact (or facts) | |
| c to help students learn a concept | |
| d to help students learn a relationship | |
| e to help students learn a theory/model | |

Process:

| | |
|---|---|
| f to help students learn how to use a standard laboratory instrument, or to set up and use a standard piece of apparatus | |
| g to help students learn how to carry out a standard procedure | |
| h to help students learn how to plan an investigation to address a specific question or problem | |
| i to help students learn how to process data | |
| j to help students learn how to use data to support a conclusion | |
| k to help students learn how to communicate the results of their work | |

Table 1. *Dimension A: Intended learning outcome. Coding categories*

Some of the terms used here may be worth clarifying briefly. In b, a 'fact' means a statement which can be readily agreed, such as that pure water boils at (or near to) 100°C, or that common salt dissolves in water whilst chalk does not. In d, a 'relationship' might be a pattern or regularity in the behaviour of a set of objects or substances, or an empirical law.

Many practical tasks are likely to have more than one of these learning objectives. It is also unlikely that some (like k) would ever be the sole objective of a practical task. In classifying a task by its learning objective(s), it is more useful if the focus is on the most important objective or objectives rather than identifying all the possible objectives which the task might be said to address.

## 5.2 Dimension B1: Design features of task

The second dimension along which practical tasks need to be classified concerns the design features of the task.

*Sub-dimension B1.1: What students are intended to do with objects and observables*

Some practical tasks require students to *use* an instrument, or a laboratory device, or a standard laboratory procedure. Others ask students to *present* an object so as to *display* certain features of it clearly, for example in a dissection of a flowering plant. Some practical tasks require the student to *make* something, for example a physical object or a material (e.g. a chemical substance), or to make an event occur. The fourth, and perhaps the largest, category of practical tasks is those which require the student to *observe* something. The observation may be of an object, or of a material, or of an event, or of a physical quantity (or variable) associated with an object, or material, or event. Also this observation may be qualitative (e.g. an observation of colour), or semi-quantitative (noting if something is large, or small), or quantitative (i.e. a *measurement*). Some examples of practical tasks of each of these kinds are shown in Appendix 1.

This aspect of a practical task can be coded using Table 2. Note how this table can also be used to provide additional information, by indicating whether the source of data which the students acquire comes from the real world, inside or outside the laboratory, or from a representation of the real world, such as a video recording or computer simulation. Also, in the case of the 'observe' categories, we can indicate whether the observation is qualitative, semi-quantitative, or quantitative, by using the codes Ql, SQt, and Qt, rather than a simple tick, in the appropriate boxes.



| What students are intended to do with objects and observables | | Source of data acquired by students (tick as appropriate) | | | |
|---|---|---|---|---|---|
| | | from real world | | from video | from computer or CD-ROM |
| | | inside laboratory | outside laboratory | | |
| use | an observation or measuring instrument | | | | |
| | a laboratory device or arrangement | | | | |
| | a laboratory procedure | | | | |
| present or display | an object | | | | |
| make | an object | | | | |
| | a material | | | | |
| | an event occur | | | | |
| observe | an object | | | | |
| | a material | | | | |
| | an event | | | | |
| | a quantity | | | | |

Table 2 *Sub-dimension B1.1: What students are intended to do with objects and observables. Coding categories*

In Table 2, although all the coding categories are expressed in the singular (an object, a material, etc.), this should also be taken to include the plural, for example, where a practical task involves making several objects or materials, or observing more than one object, material, event, or quantity. Also, for many practical tasks, it is obvious that more than one box in Table 2 will apply. For example, measuring a physical quantity ('observe a quantity') necessarily involves using a measuring instrument. But for some tasks coded as 'observe a quantity' this will not be the case. So the combination of codes gives a fuller picture of the requirements of the task.

*Sub-dimension B1.2: What students are intended to do with ideas*

Practical tasks do not only involve observation and/or manipulation of objects and materials. They also involve the students in using, applying, and perhaps extending, their ideas. That is, in addition to 'work with the hands', practical work also requires 'work with the head'. As we have said above, the central role of practical work in science education stems from its power to bridge the two domains of observables and ideas. So a practical work task can also be classified according to what the students are intended to do with ideas.

Some practical tasks simply require *direct reporting* of observations, though, of course, the selection of features to observe and record is inevitably influenced by the teacher's and/or the student's ideas about the task and its purpose. Other tasks require the student to *identify a pattern*, or regularity, in the behaviour of the objects or events observed. One particular type of 'pattern' which is common (and so worth keeping as a separate category) is a *relationship between objects*, or between *physical quantities* (variables). Another type of practical task requires students to *'invent' or 'discover' a new concept*. We find it difficult to give a concise label for this category, and might seem to be hedging our bets between an empiricist view and a radical constructivist one by using both the words 'invent' and 'discover'. We are thinking here of practical tasks in which the first step is to realise the need for a new parameter which allows a model (usually a quantitative one) to fit better with the data; the second step is then to construct a meaning for this parameter which then becomes a 'new' physical quantity, or 'new' concept. We think this second stage is likely to be teacher-mediated in almost all cases. Practical work of this type is very rare at school level, though it may be more common in the research context.

Some practical tasks focus on *determining the value of a quantity*, using an indirect method. This is distinctly different from direct measurement using a single measuring device. Here students are applying their ideas to obtain a numerical value of the quantity from a number of other, more fundamental quantities, which *can* be measured directly. Another group of tasks is those which involve *testing predictions*. In such tasks, a prediction may be simply a guess, or it may be deduced from a more formal understanding of the situation, such as an empirical law, or a theory (or model). We are using the word 'testing' loosely here, to mean seeking a match between prediction and observation. We do not want to imply that we think practical tasks in the teaching laboratory provide 'severe tests' of well-established ideas! Usually the real task for the student is to 'produce the phenomenon', that is, to



succeed in producing the outcome predicted by a well-established scientific explanation. Finally, some practical tasks are about *accounting for observations*, either by relating them to a given explanation or by proposing an explanation. An 'explanation' might be an empirical law, or a general theory, or a model derived from a general theory, or general principles derived from a theoretical framework. In some tasks, the explanatory ideas are known in advance and the student is expected to use these to account for what is observed, perhaps extending or modifying the framework of ideas. A variant of this is where two (or more) possible explanations are proposed and the task is to decide which accounts better (or best) for the data. In other tasks, the observations come first, and the student is expected to select an explanation from his/her existing knowledge, or perhaps to extend this to develop an ex-

| What students are intended to do with ideas | | Tools to be used for processing information (tick as appropriate) | | |
|---|---|---|---|---|
| | | manual | pocket calculator | computer |
| report observation(s) | | | | |
| identify a pattern | | | | |
| explore relation between | objects | | | |
| | physical quantities (variables) | | | |
| | objects and physical quantities | | | |
| 'invent' (or 'discover') a new concept (physical quantity, or entity) | | | | |
| determine the value of a quantity which is not measured directly | | | | |
| test a prediction | from a guess | | | |
| | from a law | | | |
| | from a theory (or a model based on a theoretical framework) | | | |
| account for observations | in terms of a given explanation | | | |
| | by choosing between two (or more) given explanations | | | |
| | by proposing an explanation | | | |

Table 3 *Sub-dimension B1.2: what students are intended to do with ideas. Coding categories*

| | |
|---|---|
| a What the students are intended to do with ideas arises from what they are intended to do with objects; | |
| b What the students are intended to do with objects arises from what they are intended to do with ideas | |
| c There is no clear relationship between what the students are intended to do with objects and with ideas | |

Table 4 *Sub-dimension B1.3: objects- or ideas- driven? Coding categories*

| Aspect of practical task | Specified by teacher | Decided through teacher-student discussion | Chosen by students |
|---|---|---|---|
| | (tick as appropriate) | | |
| Question to be addressed | | | |
| Equipment to be used | | | |
| Procedure to be followed | | | |
| Methods of handling data collected | | | |
| Interpretation of results | | | |

Table 5 *Sub-dimension B1.4: degree of openness/closure of a practical task. Coding categories*

planation. Some examples of practical tasks of each of these kinds are shown in Appendix 2.

This aspect of a practical task can be coded using Table 3. Again this table can be used to provide additional information, by placing ticks in the appropriate column to indicate the kinds of tools available to students for processing the information they obtain.

*Sub-dimension B1.3: Objects- or ideas-driven?*
A third sub-dimension of the design of a practical task concerns the relationship between the two domains: of objects and observables, and of ideas. Some tasks are presented in an 'objects-driven' way: the student is required to carry out some operations on objects from which, it is hoped, ideas will emerge. Other tasks are presented in an 'ideas-driven' way: the operations on objects are specifically undertaken to explore some ideas which have been stated in advance. Of course, to some extent, all observation is guided by the ideas of the observer (or the teacher giving the instructions). This dimension of the 'map' is intended simply to reflect the *emphasis* in the practical work task. The coding categories are shown in Table 4.



*Sub-dimension B1.4: Degree of openness/closure*
Practical tasks can differ widely in the extent to which the student is able (or required) to take decisions about aspects of the task. So the fourth sub-dimension of the design of a practical task distinguishes between 'open' and more 'closed' tasks, by looking at who takes the decisions about different aspects of the design and conduct of the task. The pattern of ticks in Table 5 provides an indication of the degree of openness or closure of the task.

*Sub-dimension B1.5: Nature of student involvement*
The fifth and final sub-dimension of task design concerns the nature of student involvement in the practical task. The coding categories are shown in Table 6.

| | |
|---|---|
| a demonstrated by teacher; students observe | |
| b demonstrated by teacher; students observe and assist as directed (e.g. in making observations or measurements) | |
| c carried out by students in small groups | |
| d carried out by individual students | |

Table 6 *Sub-dimension B1.5: nature of student involvement. Coding categories*

## 5.3 Dimension B2: Context of the task

In addition to the wide variations possible in the design of practical tasks, there can also be wide differences in the context within which the task is carried out. Four sub-dimensions relating to task context can be identified: the amount of time that is given to the task, the people with whom the student is expected to interact whilst carrying out the task, the way in which information is given to the student on the task, and the type of apparatus involved in carrying out the task.

Compared with dimension B1 of the 'map', these dimensions and their associated coding categories are largely self-explanatory. They are summarised in Tables 7-10.

| | | |
|---|---|---|
| a | very short (less than 20 minutes) | |
| b | short (one science lesson, say, up to 80 minutes) | |
| c | medium (2-3 science lessons) | |
| d | long (2 weeks or more) | |

Table 7 *Sub-dimension B2.1: duration of task. Coding categories*

| | | |
|---|---|---|
| a | other students carrying out the same practical task | |
| b | other students who have already completed the task | |
| c | teacher | |
| d | more advanced students (demonstrators, etc.) | |
| e | others (technician, glassblower, etc.) | |

Table 8 *Sub-dimension B2.2: people with whom the student interacts. Coding categories*

| | | |
|---|---|---|
| a | oral instructions | |
| b | instructions on blackboard/whiteboard/OHP | |
| c | guiding worksheet | |
| d | textbook(s) | |
| e | other (e.g. data book, data base, instruction manual, etc.) | |

Table 9 *Sub-dimension B2.3: information given to the student on the task. Coding categories*

| | | |
|---|---|---|
| a | demonstrated by teacher; students observe | |
| a | standard laboratory equipment | |
| b | standard laboratory equipment + interface to computer | |
| c | everyday equipment (kitchen scales, domestic materials...) | |

Table 10 *Sub-dimension B2.4: type of apparatus involved. Coding categories*



### 5.4 Dimension B3: The student's record of work on the task

Finally, practical tasks can differ in the ways in which the student is expected to produce a record of work on the task, the purposes of such a record and the audience for whom it is produced. As with dimension B2, the sub-dimensions of B3 and their associated coding categories are largely self-explanatory. They are summarised in Tables 11-13.

| | | |
|---|---|---|
| a | no written record | |
| b | notes | |
| c | completion of printed worksheet | |
| d | written account (using given structure and format) | |

Table 11 *Sub-dimension B3.1: nature of student's record of work on the task. Coding categories*

| | | |
|---|---|---|
| a | to assist students in learning science content or process | |
| b | to provide evidence that the task has been carried out | |
| c | as a basis for assessing the student's performance | |
| d | as a record which the student can use to revise for tests or examinations | |
| e | to help students learn how to write a scientific report | |

Table 12 *Sub-dimension B3.2: purpose of student's record of work on the task. Coding categories*

| | | |
|---|---|---|
| a | the student | |
| b | teacher | |
| c | other students | |
| d | other | |

Table 13 *Sub-dimension B3.3: audience for student's record of work on the task. Coding categories*

## 6 Possible uses of a 'map' of practical work

A coding proforma for describing in detail the characteristics of any practical task can be assembled by collating Tables 1-13 above. This can be used to produce a profile of the salient features of any given practical task. What, then, might be this classification and coding system be used for? First, it can be used to identify similarities and differences in the kinds of practical work used in school science courses, perhaps to compare the types used at different ages or stages, or in the different science disciplines. In this way, for example, we might discover that some types appeared to be underused, or overused. The coding categories may also suggest questions which we might ask about practical work. Does a course make as much use as we might wish of more open-ended tasks? What is the degree of openness in the tasks used, and how does this compare with our intentions?

The 'map' also provides us with a clearer basis for addressing questions of the effectiveness of practical work. From this discussion of dimensions, sub-dimensions and coding categories, it should be clear that there is a very wide variety of types of practical task which might be used in teaching and learning science. It clearly does not make sense to ask in general: is practical work an effective means of teaching science? For any given task, however, we can use the 'map' to provide a full description of the characteristics of the task. Then we are in a better position to carry out research to see whether students actually do the things (with objects and with ideas) that we want them to – and, if we find they do not, we can consider whether adjustments to the task design or the context within which it is carried out, by modifying it on one or more of the sub-dimensions which relate to these, might make it more effective in attaining its goals. In this way we may be able, over time, to make gradual progress towards a more efective use of practical work in science courses at all levels.

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## Appendix 1 Coding categories for sub-dimension B1.1 with examples of each

| What students are expected to do with objects and observable things | *Examples* |
|---|---|
| use an observation or measuring instrument | *use a microscope to look at onion skin cells*<br>*use a cathode ray oscilloscope (CRO) to look at some signal waveforms*<br>*use a burette to deliver measured volumes of a liquid* |
| use a laboratory device or arrangement | *set up distillation apparatus to separate two miscible liquids*<br>*use a dissecting kit/scalpel to remove a muscle from a chicken wing*<br>*set up a filter funnel to separate a solid from a liquid* |
| use a laboratory procedure | *carry out a recrystallisation of a compound to produce a purer sample*<br>*set up a control for a biological investigation*<br>*follow a standard schedule for qualitative analysis of a sample of an unknown inorganic compound* |
| present or display an object | *carry out a dissection of a biological specimen to display the main features of interest*<br>*display a collection of geological specimens to illustrate a particular feature* |
| make an object | *make a microscope slide to display the cells of a given specimen*<br>*make an electric circuit from a given circuit diagram* |
| make a material | *synthesise a particular chemical substance* |
| make an event occur | *tune an electric circuit containing a capacitor (C) and an inductor (L) to show resonance* |
| observe an object | *note and record the pattern of iron filings sprinkled around a bar magnet*<br>*look at some fossil specimens*<br>*inspect some rock samples with a hand lens for evidence of volcanic origins* |
| observe a material | *note and record the shape of crystals of copper sulphate*<br>*note and record the physical properties of a sample of polythene* |
| observe an event | *record the manner in which an animal (an invertebrate, a fish) moves*<br>*note what happens when a piece of sodium is placed in water*<br>*pass a ray of white light through a prism and note the spectrum produced*<br>*make observations of the germination and growth of a broad bean*<br>*note whether an object floats or sinks when placed in water* |
| observe a quantity | *measure the resistance of a piece of wire*<br>*measure the volume of an acid solution needed to neutralise a given volume of an alkali solution*<br>*measure the density of a sample of a solid material*<br>*measure the length of a spring with different loads hanging from it*<br>*measure the melting point of a substance*<br>*observe the change in temperature of water in an insulated container over a period of time* |

## Appendix 2 Coding categories for sub-dimension B1.2 with examples of each

| What students are expected to do with ideas | *Examples* |
|---|---|
| report observation(s) | *describe in detail how a fish moves*<br>*describe the shape of crystals of a given substance* |
| identify a pattern | *compare the measured IR spectrum of an organic compound to known IR spectra in order to identify it*<br>*note the different plant and animal species found at different levels of a seashore habitat.*<br>*compare the outcome of a test for glucose on a sample of foodstuff with a previously observed positive test*<br>*note the regular changes in the appearance of the moon over a 29 day cycle*<br>*identify the objects and variables in an environment which are involved in some interactions of interest within that environment* |
| explore relation between objects | *note that a pinhole camera produces an inverted image on the screen* |
| explore relation between physical quantities | *find out how the [extension – increase of length] of a spring depends on the [load -mass] attached to it*<br>*find out how temperature and concentration of reagents affect the rate of an enzyme reaction* |
| explore relation between objects and physical quantities | *compare rates of reaction of a selection of metals with dilute acid*<br>*investigate the effect of different drinks (tea, coffee, cocoa, etc.) on rate of heartbeat* |
| 'invent' (or 'discover') a new concept (physical quantity, or entity) | *identify the need for (or the usefulness of) the quantity defined as energy/time (power) in accounting for a set of observations*<br>*identify that, for a weak acid, the ratio: log ([$H^+$].[$A^-$]/[HA]) is constant and can be used to characterise the strength of the acid* |
| determine the value of a quantity which is not measured directly | *measure the acceleration due to gravity using the relationship T = 2π\R(\F(l,g)) for a simple pendulum*<br>*measure the thermal conductivity of a material*<br>*determine the number of molecules of water of crystallisation associated with each molecule of a salt using volumetric analysis* |
| test a prediction based on a guess | *test the prediction that rubber-soled shoes provide better 'grip' on a wooden floor*<br>*guess that a sample of soil is mainly limestone and test for effervescence when dilute acid is added* |
| test a prediction from a law | *test whether the increase in length (extension) of a piece of elastic is directly proportional to the load applied, up to a limit (as predicted by Hooke's Law)*<br>*test whether the electric current through a given conductor is proportional to the applied p.d. (as predicted by Ohm's Law)* |
| test a prediction from a theory (or a model based on a theoretical framework) | *a model of the mechanism of a chemical reaction predicts a certain relationship between rate of reaction and temperature; test this by comparing it with what is actually observed*<br>*predict the pH of a solution of ethanoic acid of given concentration using the formula: pH = \F(1,2) ($pK_a$ – log [c]) and then check this by measurement*<br>*theory of fluid flow predicts that the volume of fluid per second (Q) flowing through a pipe is related to pressure difference (P), radius (r) and length (l) by the equation: Q = \F(Pπr⁴,8ηl), where h is the viscosity of the liquid. Carry out a series of measurements to test this relationship in the case of water* |
| account for observations in terms of a given explanation | *explain similarities and differences between related species of birds in terms of a given account of their evolution*<br>*explain observations in some displacement reactions (metal/metal salt solution) in terms of the reactivity series for metals* |
| account for observations by choosing between two (or more) given explanations | *is the behaviour observed when the temperature of a sample of air is raised better explained by saying that 'hot air rises' or 'air expands when heated'* |
| account for observations by proposing an explanation | *from observation of the objects and variables in an environment, propose a model to explain some aspect of the interactions within that environment*<br>*measure the temperature of a sample of water in a calorimeter over a period of minutes as it is heated by an immersion heater. Explain the shape of the temperature-time graph produced* |

## Appendix 3 Practical work task: Profile Form

### A Intended learning outcome (learning objective)

| | |
|---|---|
| a to help students identify objects and phenomena and become familiar with them | |
| b to help students learn a fact (or facts) | |
| c to help students learn a concept | |
| d to help students learn a relationship | |
| e to help students learn a theory/model | |

| | |
|---|---|
| f to help students learn how to use a standard laboratory instrument, or to set up and use a standard piece of apparatus | |
| g to help students learn how to carry out a standard procedure | |
| h to help students learn how to plan an investigation to address a specific question or problem | |
| i to help students learn how to process data | |
| j to help students learn how to use data to support a conclusion | |
| k to help students learn how to communicate the results of their work | |

### B1.1 What students are intended to do with objects and observables

| | | |
|---|---|---|
| use | an observation or measuring instrument | a |
| | a laboratory device or arrangement | b |
| | a laboratory procedure | c |
| present or display | an object | d |
| make | an object | e |
| | a material | f |
| | an event occur | g |
| observe | an object | h |
| | a material | i |
| | an event | j |
| | a quantity | k |



### B1.2 What students are intended to do with ideas

| | | |
|---|---|---|
| report observation(s) | | a |
| identify a pattern | | b |
| explore relation between | objects | c |
| | physical quantities (variables) | d |
| | objects and physical quantities | e |
| invent' (or 'discover') a new concept (physical quantity, or entity) | | f |
| determine the value of a quantity which is not measured directly | | g |
| test a prediction | from a guess | h |
| | from a law | i |
| | from a theory (or model based on a theoretical framework) | j |
| account for observations | in terms of a given explanation | k |
| | by choosing between two (or more) given explanations | l |
| | by proposing an explanation | m |

### B1.3 Objects- or Ideas-driven?

| | |
|---|---|
| a What the students are intended to do with ideas arises from what they are intended to do with objects | |
| b What the students are intended to do with objects arises from what they are intended to do with ideas | |
| c There is no clear relationship between what the students are intended to do with objects and with ideas | |

### B1.4 Degree of openness/closure

| Aspect of practical task | Specified by teacher | Decided by teacher-student discussion | Chosen by students |
|---|---|---|---|
| Question to be addressed | | | |
| Equipment to be used | | | |
| Procedure to be followed | | | |
| Methods of handling data collected | | | |
| Interpretation of results | | | |

### B1.5 Nature of student involvement

| | | |
|---|---|---|
| a | demonstrated by teacher; students observe | |
| b | demonstrated by teacher; students observe and assist as directed | |
| c | carried out by students in small groups | |
| d | carried out by individual students | |

### B2.1 Duration

| | | |
|---|---|---|
| a | very short (less than 20 minutes) | |
| b | short (one science lesson, say, up to 80 minutes) | |
| c | medium (2-3 science lessons) | |
| d | long (2 weeks or more) | |

### B2.2 People with whom student interacts

| | | |
|---|---|---|
| a | other students carrying out the same practical task | |
| b | other students who have already completed the task | |
| c | teacher | |
| d | more advanced students (demonstrators, etc.) | |
| e | others (technician, etc.) | |

### B2.3 Information given to the student on the task

| | | |
|---|---|---|
| a | oral instructions | |
| b | instructions on blackboard/whiteboard/OHP | |
| c | guiding worksheet | |
| d | textbook(s) | |
| e | other (e.g. data book, data base, instruction manual, etc.) | |

### B2.4 Type of apparatus involved

| | | |
|---|---|---|
| a | standard laboratory equipment | |
| b | standard laboratory equipment + interface to computer | |
| c | everyday equipment (kitchen scales, domestic materials...) | |



### B3.1 Nature of student's record of work on task

| | | |
|---|---|---|
| a | no written record | |
| b | notes | |
| c | completion of printed worksheet | |
| d | written account (using given structure and format) | |
| e | written account (free format) | |

### B3.2 Purpose of record

| | | |
|---|---|---|
| a | to assist students in learning science content or process | |
| b | to provide evidence that the task has been carried out | |
| c | as a basis for assessing the student's performance | |
| d | as a record which the student can use to revise for tests or examinations | |
| e | to help students learn how to write a scientific report | |

### B3.3 Audience for record

| | | |
|---|---|---|
| a | the student | |
| b | the teacher | |
| c | other students | |
| d | other | |