# Effective practical work: 'hands on' and 'minds on'

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The approach to practical work which we advocate and illustrate in this book is based on a fundamental principle – namely that students need to be helped to think about what they are doing and learning in a practical. As we will show below, the evidence from secondary science classrooms is that it is far too often the case that even students who are reasonably proficient at undertaking practical work have little understanding of why they are doing what they are doing or of what they are supposed to be learning from it.

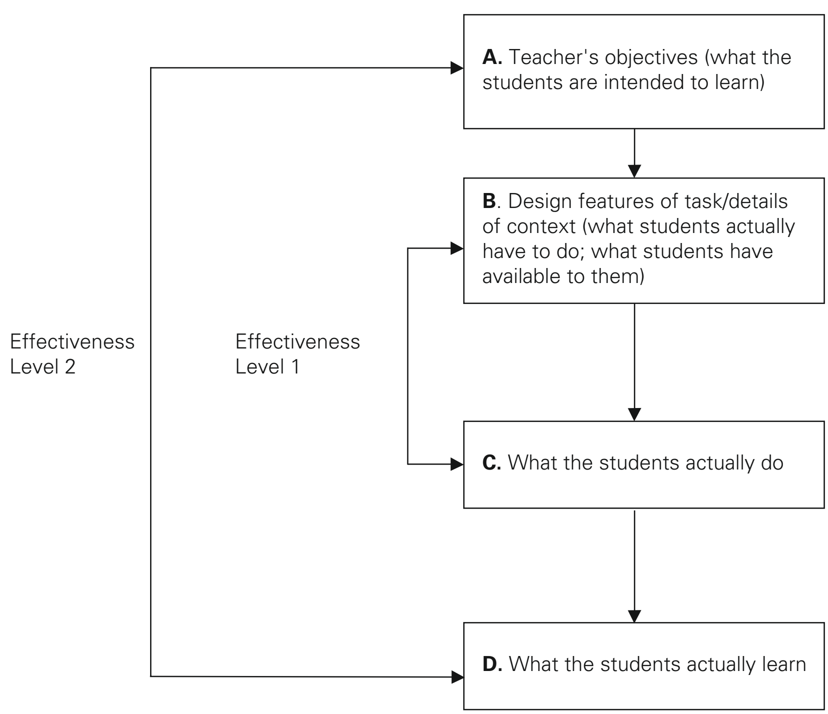
Such practical work can still have some value. Students may develop certain skills and they may enjoy their science lessons. However, our belief is that practical work in school science can achieve much more than this.

## 2.1 The 'hands on' and 'minds on' model that we advocate

As we discussed in Chapter 1, practical work encompasses a broad range of activities that can have widely differing aims and objectives. The framework used here to determine the effectiveness of practical work is one that was developed and used by Abrahams and Millar (2008) in a previous study of the effectiveness of practical work. It draws on a model (Figure 2.1) proposed by Millar et al. (1999) for evaluating a practical task.

This model considers the effectiveness of a specific task *relative* to the aims and intentions of the teacher and, as such, the starting point (Box A) is the teacher's learning

**Figure 2.1** Model of the process of design and evaluation of a practical task.



objectives in terms of what it is they want the students to learn. After deciding what they want the students to learn, the next step (Box B) is for the teacher to design a specific practical task that, they believe, has the potential to enable the students to achieve the desired learning objectives. As the students might not do exactly what was intended by the teacher, the next step (Box C) considers what it is that the students actually do as they undertake the task. There are various reasons as to why the students might not actually do what their teacher intended; for example, they might not understand the instructions or, even if they do and adhere to them meticulously, faulty apparatus can prevent them from doing what was intended by the teacher. Alternatively, even if the task is carried out as the teacher intends and all of the apparatus functions as intended, the students still might not engage mentally with the task using the ideas that the teacher had intended them to use.

The final stage of the model (Box D) is thus concerned with what the students learn as a consequence of undertaking the task. This model allows the question of the effectiveness of a specific practical task to be considered at two separate levels. We can consider the effectiveness of the task (at level 1) in terms of the match – or alignment – between what the teacher intended students to *do* and what they actually do and the effectiveness of the task (at level 2) as being the match – or alignment – between what the teacher intended the students to *learn* and what they actually learn. 'Level 1 effectiveness' is therefore concerned with the relationship between Boxes B and C in Figure 2.1 (doing), while 'level 2 effectiveness' is concerned with the relationship between Boxes A and D (learning).

This model can therefore be used to address the following two questions:

1 Does the practical task enable the students to do the things the teacher intended them to do?

2 Does the practical task enable the students to learn what their teacher intended?

By combining this two-level model of effectiveness with a two-domain model of knowledge developed by Tiberghien (2000), in which there is a domain of observable objects and events (o) and a domain of ideas (i), it becomes possible to consider each of the two levels of effectiveness in terms of these two distinct domains.

These two levels of effectiveness, each of which can be considered with respect to the two distinct domains of knowledge, can be represented (Table 2.1) using a 2 × 2 effectiveness matrix.

**Table 2.1** The 2 × 2 effectiveness matrix for practical work

| A task is effective | in the domain of observables (Domain o) | in the domain of ideas (Domain i) |
|---|---|---|
| **at level 1 (what students do)** | If students can set up the equipment and operate it in such a manner as to undertake what the teacher intended. | If students can think about the task using the ideas and scientific vocabulary intended by the teacher. |
| **at level 2 (what students learn)** | If students can discover patterns within their observations/data and describe these; describe the procedure used and in future set up and operate similar equipment. | If students understand their observations/data by being able to link them, using the ideas and vocabulary intended by the teacher, with the correct scientific theory. |

The effectiveness of any practical task can now be analysed and discussed in terms of two principal levels with each level being further divided into two domains. To illustrate the use of a 2 × 2 effectiveness matrix, consider its application to a practical task that was observed in which students study chromatographic separation of colours in dyes (Table 2.2).

**Table 2.2** The 2 × 2 effectiveness matrix for a practical task involving an investigation of the chromatographic separation of colours in dyes

| A task is effective | in the domain of observables (Domain o) | in the domain of ideas (Domain i) |
|---|---|---|
| **at level 1 (what students do)** | If students can construct a separation column to match the provided instructions; observe how a drop of dye placed on the filter paper spreads out as liquid seeps up the paper, so that several spots or streaks can be seen. | If students can talk about different substances moving up the paper at different speeds; several spots implying several substances; dyes as mixtures of substances. |
| **at level 2 (what students learn)** | If students can set up and use a chromatographic separation column. Students state that separated colours are different dyes that made up their initial dye; this can be used to separate a mixture of dyes into its components; that the pattern from an unknown dye can be compared with that of a known one to help identify the unknown one. | If students can state that different substances move up a chromatography column at different speeds; this can be used to see if something contains more than one substance; this can be used to separate the components substances in a mixture; that the chromatogram of an unknown sample can be compared with those of known samples to see if they contain the same component substances. |

The four cells of Tables 2.1 and 2.2 are not independent as a task is unlikely to be effective at level 2:i unless it was also effective at levels 1:i, and, most likely, also at levels 1:o and 2:o. Such a framework provides an effective means of determining the effectiveness of any practical task in terms of the four cells of Table 2.1.

## 2.2 Using the model in practice

So that's our model for effective practical work. How useful is it in practice?

The model was used by us in an evaluation we undertook, with Rachael Sharpe, of the 'Getting Practical: Improving Practical Work in Science' (IPWiS) project (Abrahams et al., 2011). The project was led by the Association for Science Education (ASE), which created a package of continuing professional development (CPD) materials for it. These materials were designed by a consortium and were intended to help teachers reflect on and improve: (i) the clarity of the learning outcomes associated with practical work, (ii) the effectiveness and impact of the practical work, (iii) the sustainability of this approach within their schools, allowing for ongoing improvements and (iv) the quality, rather than quantity, of practical work used.

The IPWiS project, which ran for two years and involved 200 trainers, trained over 2000 teachers from both primary and secondary schools. The initial 200 trainers attended 'Train the Trainer' events. The project then used a cascade model in which these 200 trainers then ran training sessions themselves for schoolteachers in their own local areas who, in turn, it was hoped, would cascade down the training a further level within their own schools (primary) and departments (secondary). The course was designed for flexibility and the six-hour training could be delivered through a single (whole day) six-hour session, a pair of three-hour sessions (two half-day courses) or three two-hour sessions (twilight courses) with individual trainers deciding upon which approach to use in order to best meet the needs of their local teachers.

Some training courses were run for only primary or only secondary teachers while others hosted mixed groups and this again depended on the choice of the local trainer. Teachers working at both primary and secondary levels, and at all stages of their careers, attended the training sessions. All three secondary science main subject specialisms were represented by the secondary teachers. Technicians were also encouraged to undertake the training to enable them to better understand how practical work can be improved and to enhance the support they can offer teachers in practical lessons.

Permission was asked of ten primary teachers (students aged 5–11) and twenty secondary teachers (students aged 11–18), who had registered to undertake the IPWiS training, to observe two of their practical lessons, one prior to the training, in order to provide a benchmark of their practice, and another after the training was completed, to evaluate any changes in both their and their department's use of practical work. Ian Abrahams, Michael Reiss and Rachael Sharpe undertook audio-recorded observations of lesson and interviews that were carried out with the teacher before and after the lesson. The pre-lesson interview was primarily used as a means of obtaining the teacher's account of the practical work to be observed and of his or her view of the learning objectives of the lesson. The post-lesson interview collected their reflections on the lesson and its success as a teaching and learning event. Furthermore, when the opportunities arose, other members of the department were questioned about their knowledge and understanding of the IPWiS project. In addition to audio-recording all teacher–whole class discussions and instructions, conversations between groups of students, and between students and the researcher, were also recorded. These conversations, in addition to field notes that were made, provided insights into the students' thinking not only about the task(s) that they were observed undertaking, but also with regards to their recollections of other previous practical tasks that they had undertaken.

The schools within the evaluation were selected by the Association of Science Education as 'typical' primary and comprehensive secondary schools in England, in terms of size, with locations spread geographically. A reasonably balanced coverage of subject material and age ranges was achieved – see Table 2.2. While this book is concerned with secondary science teaching, the findings for the primary teachers of science proved to have great relevance for secondary science teaching and so are included in Table 2.3.

**Table 2.3** Lesson observations by student age range and subject

| School type | Student age range | Biology | Chemistry | Physics | Other (Earth Science) |
|---|---|---|---|---|---|
| Primary | 5–7 | 2 (0) | 1 (0) | 5 (2) | 0 (0) |
| | 7–11 | 0 (2) | 1 (1) | 1 (3) | 0 (0) |
| Secondary | 11–14 | 4 (3) | 3 (3) | 6 (3) | 1 (0) |
| | 14–16 | 1 (0) | 2 (1) | 0 (0) | 0 (0) |
| | 16–18 | 1 (1) | 1 (1) | 1 (0) | 0 (0) |

Brackets indicate second round observations. Primary school 'science lessons' have been classified as biology, chemistry or physics so as to present an overview of the range of subject areas observed across all age ranges.

## 2.3 Pre-training observations

### Primary schools

What emerged from the first round of observations was how well conceived, clear and productive practical science was in most of those primary schools visited. One possible explanation for this – an explanation which could strike some as paradoxical – might be that the lessons observed were, in all but one case, taught by teachers who were not science subject specialists in the sense that the term 'science subject specialists' is understood by secondary science teachers. Indeed, not only were the teachers not science specialists but some of them spoke to us about their own difficulties with scientific ideas and the meanings of certain scientific terms (Harlen & Holroyd, 1997). As a consequence of the difficulties they themselves encountered with some aspects of science, they appeared better able to empathize with the problems that their students faced when learning about new ideas in science, and the meaning of new scientific terms, than were many secondary subject specialists.

The primary teachers used practical tasks that were tightly constrained, of the kind that have been termed 'recipe' style (Clackson & Wright, 1992) as a means of ensuring that all of their students were able to see the desired phenomenon in the time available. Furthermore, by using relatively short practical tasks, embedded within a lesson rather than taking up the entire lesson, the teachers ensured that they had sufficient time to introduce students to, and fully discuss, new scientific terms and ideas in the way that it has been suggested (Abrahams, 2011) is necessary if teaching and learning are to be effective in developing conceptual understanding. Certainly our observations suggest that primary teachers see practical work as both a 'hands on' *and* a 'minds on' activity.

The findings of these baseline observations draw attention to characteristics of current good practice in the use of practical work in primary science teaching. They suggest an understanding of the need to ensure that practical work does not just involve 'doing' with observables but also requires students to think about, and engage with, scientific ideas and terms.

## Secondary schools

The practical work that we observed throughout the twenty secondary schools was, generally speaking, effective in enabling most of the students, irrespective of their academic ability, to do what the teacher wanted them to do with observables and, in so doing, produce the required phenomena. While various factors contributed towards this effectiveness, two of the most noticeable were the use of 'recipe' style tasks, designed to reliably produce a particular phenomenon if those undertaking it adhered to the 'recipe', and the allocation of more time to the presentation, and clarification, of procedural instructions than did many of their primary colleagues.

Because a particular piece of practical work was likely to be considered as having 'failed' if the students were unable to produce the desired phenomena, teachers tended to focus their attention on ensuring that students were able to follow instructions in order to maximize the likelihood that they would all successfully produce the desired phenomena. Time constraints, and the fact that 'doing something with ideas' was not a necessary prerequisite for the successful production of phenomena, meant that when using 'recipe' style tasks teachers devoted relatively little whole class time to getting the students to do what they wanted them to do with ideas, that is, to think about the observables and phenomena they were seeing in a particular scientific way. Even when teachers did allocate time to getting the students to 'do things with ideas' the ideas were kept relatively simple to ensure that there was sufficient time not only to get the students to think about the observables and phenomena, using the intended ideas, but also to get them to produce the desired phenomena.

What emerged, as the following example illustrates, was that some tasks were observed to be little more than the unquestioning adherence to a 'recipe' in order to produce a phenomenon and/or data.

> Student: Yeah, so I'm just following the method that we've been given [indicates worksheet] and hopefully … and we've got like the results table [points to pre-printed table on the worksheet] so we'll just get them [their results] down.

Practical work was found to be more effective in getting students to learn what the teacher intended about observables and phenomena than it was in getting them to learn about ideas. A possible explanation for this is that to be effective in getting students to learn what the teacher intended about observables and phenomena requires only that the students are able at some later time (such as in an examination) to describe qualitatively what they have seen, and/or be able to formulate simple relationships about observables. Given the observed effectiveness of practical work in enabling students to produce the desired phenomena it seems reasonable to expect that most students will be able to achieve what are essentially intellectually undemanding learning objectives.

Yet while some students were able to describe their observations, and/or formulate simple relationships about the data, during, or immediately after, the practical lesson, most were unable, without assistance, to recollect more than a few examples of the practical work that they had undertaken during their time at secondary school. Indeed, when asked, their recollections were found to relate primarily to practical tasks that were, in some sense, ‘unusual’; furthermore, these recollections related almost exclusively to what had made that particular task – or something associated with it – unusual rather than to what the teacher might have intended them to learn and recollect.

For example, students recollected the burning of magnesium ribbon insofar as they remembered that it had been visually spectacular but there was no evidence that such ‘memorable events’ (White, 1979) provided any anchor point, or ‘trigger’, for associated scientific ideas that might have been learnt within the teaching sequence in which the practical lesson was embedded. Similarly, here is a short extract of a conversation one of us had with students during a lesson:

Researcher: Can you remember any practicals you’ve done since you’ve been at school?
Student 1: Yeah [talking to Student 2] do you remember in Year 7 [students aged 11–12], that collapsing can?
Researcher: Collapsing can?
Student 2: Oh yeah, they put it in something.
Student 1: And put it in cold water.
Student 2: Yeah.
Researcher: What did you learn from that?
Student 1: I don’t know, I didn’t learn anything, it was just quite funny.
Student 2: When I did it, it didn’t work [implode] for some strange reason.

In terms of getting students to learn about the ideas intended by the teacher, all of the observed practical lessons were either wholly or to a large extent ineffective. One way of helping to understand the reason for this is to think of the ‘learning about ideas’ as being the last step in a process that depends necessarily on the students having succeeded not only in doing and learning what the teacher intended about observables and phenomena but also in doing what the teacher intended with ideas. A failure adequately to achieve any one, or more, of these prerequisites adversely affects the students’ ability to learn about the ideas intended by the teacher within that particular practical lesson. Indeed, the strong emphasis placed by the teachers on getting the students to ‘produce the phenomena’ resulted in them not including in their lesson plans the need to devote teaching time specifically to providing the conceptual ‘scaffold’ that is required to help with the development of the students’ conceptual understanding.

## 2.4 Post-training findings

### Doing with objects, materials and ideas

The overall impression to emerge from the observations of lessons after the teachers had completed their IPWiS training was that primary and secondary teachers continued to see the production of the intended phenomenon, and/or collection of the intended data, by the majority of students in their class, as being central to the success of a practical lesson. In this respect the continued widespread use of 'recipe' style tasks meant that in both primary and secondary schools practical work remained highly effective in enabling most of the students to successfully do what their teachers wanted them to, using the objects and materials provided.

While 'doing with objects and materials' is self-explanatory, 'doing with ideas' is less self-evident and refers to the process of using scientific terminology as well as thinking and talking about objects and materials, using theoretical entities or constructs that are not themselves directly observable. And while the overwhelming majority of the practical work we observed in our post-training visits, in both primary and secondary schools, was effective in enabling students to do what their teacher wanted them to do with objects and materials, primary teachers were, compared to their secondary colleagues, more effective in getting their students to 'do with ideas'. This was essentially as a result of teachers devoting whole class time to students' learning the meaning of the new scientific words or concepts rather than their teachers being more effective in getting the students to talk about objects and materials in terms of theoretical entities or constructs that are not themselves directly observable.

### Primary school impact

The most notable finding to emerge from the post-training observations of primary school teachers was the extent to which there was a feeling that the IPWiS 'message' was nothing new and that primary teachers had been doing just what IPWiS was suggesting teachers do, in some cases, for many years. As one primary teacher explained:

> A lot of the stuff we'd already had training on before … I just feel that a lot of the stuff that was covered [on the IPWiS training] was things that on other science training [courses] I'd been on I'd already learnt.

Yet despite this, some of the primary teachers, as the following example illustrates, spoke of being more aware of the need to ensure that their practical lessons contained fewer learning objectives than might previously have been the case:

> It made me focus more on specific objectives. I think before [the IPWiS training] I would try to do too much in the whole lesson.

Overall the findings showed that while the IPWiS training had been effective in getting primary teachers to think more critically about some of the issues relating to the effectiveness of practical work, it had had little impact on their actual practice in terms of doing with objects, materials and ideas. This should not be seen as a criticism of either the primary teachers themselves or the IPWiS training, but rather reflects the fact that much of what IPWiS set out to achieve, certainly in terms of 'doing with ideas', was already taking place in primary science lessons.

## Secondary school impact

The impact of the IPWiS training on secondary teachers varied considerably and this variation was seen to depend on not only who undertook the training, their role/seniority within the department and their enthusiasm for the project, but also the extent to which the aims of the project had active support from members of the school's Senior Management Team (SMT).

Upland Community College (their head teacher gave permission to use their name) clearly shows what can be achieved when conditions are close to 'ideal'. In this case it was the head of science who undertook the training, saw tremendous value in the material being delivered and returned to the school keen to implement the IPWiS project ideas across the department as a whole. The SMT within the school was fully committed to supporting the full-scale implementation of the required changes in the Science Department's schemes of work in order to bring them more into line with the ideas about the use of practical work as suggested by the IPWiS training. The SMT also provided time to enable a full and effective cascade of ideas to occur not only for the members of the school's own science department but also for the teachers of science in the school's feeder primary schools.

A very noticeable change in classroom practice evident as, compared with the first (pre-training) observation, the second lesson now only focused on a few, clearly identified, learning objectives, and was very much a 'hands-on' *and* 'minds-on' lesson. The structure of the lesson had also changed so that rather than the practical task taking up a large proportion of the lesson it was, in the post-training lesson, relatively short and embedded within the lesson and was only started *after* the students had engaged with the ideas that would enable them to understand their observations. Other members of the department showed in discussions that they too, as a result of the training being cascaded down to them, were familiar with the ideas of the IPWiS project. Not only did they talk positively about changes to the way that they now used practical work but they also said that they had begun to undertake regular peer observations of each other's use of practical work that were designed to help reinforce the IPWiS message within the department.

While Uplands shows what can be achieved, the impact in the other secondary schools was much less evident. While there were various reasons for this, including the seniority and role of the person undertaking the training, another particularly noticeable problem in getting the IPWiS 'message' heard in schools was the evident weakness of the cascade model of training used within the IPWiS project.

## 2.5 Conclusions and implications for undertaking practical work

Concentrating on the secondary schools, a number of findings emerged from the evaluation. The first is the fact that the IPWiS project did bring about changes in both the use and effectiveness of practical work. However, the extent of that change varied widely and while many secondary teachers appeared to understand the IPWiS project 'message' and *claimed* that it had changed their practice, our evaluation suggested that for most secondary teachers we observed their actual use of practical work remained relatively unchanged as a result of the training.

Secondly, despite the fact that many of the secondary teachers included the learning of scientific ideas amongst their learning objectives for practical lessons, there was little evidence to show that they recognized the need to *explicitly* plan how they wanted to get their students to learn about ideas. This was in marked contrast to the way in which their lesson plans, and recipe style tasks, typically made explicit what they wanted their students to do with objects.

Thirdly, the impact of the IPWiS project within a particular school was seen to depend upon who undertook the training, for example, whether they were a head of department or a newly qualified teacher (NQT), and the extent to which the school's SMT was supportive and proactive in wanting the IPWiS project ideas to be implemented.

The principal implication of all this is that while the IPWiS project was successful in raising secondary science teachers' *awareness* of how to improve the quality of the practical science work, more needs to be done to help secondary science teachers to get their students to think about the scientific ideas they are meant to be learning in lessons that centred on practical work. That is why we have written this book.

Each of the six chapters that follow has twelve session guides (essentially, lesson plans) for a particular practical. Three of these chapters are intended to be used with 11- to 14-year-old students (one chapter on biology, one on chemistry and one on physics) and three with 14- to 16-year-olds (again, one chapter on biology, one on chemistry and one on physics). Each session guide clearly explains the learning objectives for the practical and the procedure that students need to follow. An equipment list is provided along with things for the teacher to keep in mind and issues for discussion. Any health and safety issues are addressed. A key feature of these chapters is that each practical has an 'Effectiveness matrix' which clearly indicates what students should do and what they should learn, both while undertaking the practical and as a result of undertaking it.

Of course, it is not the intention that you, as the teacher, will get your students to undertake all these practicals. A whole range of factors will influence the practicals that you choose to use, including the curriculum that your students are following and your own preferences. In addition, some of the practicals included here for 11- to 14-year-olds may have been undertaken by students near the end of their previous phase of schooling – though the effectiveness matrix often means that students are encouraged to think about the practical work more than they may previously have done. Of course, if students have undertaken the practical or a similar one, their thoughts can be elicited. Even if they haven't, it is often a good idea to get students to talk about what they have already learnt that may be relevant and to think about what might happen in advance of undertaking the practical.

Although we have concentrated on the value of the effectiveness matrix, with its emphasis on students thinking about what they are doing as well as doing it and making observations, practical work can be used in other ways. For instance, it can be used to strengthen mathematical skills and skills of teamwork and communication. In addition, some practicals have cross-curricular potential, for example, in relation to geography.

The effectiveness matrices are based on Table 2.1. They have been designed to help (some readers may prefer the word 'require') students to think about what they are doing and what they are learning from undertaking the practical. Please note that while some practicals have entries in all four 'cells' of the effectiveness matrix, this is *not* always the case. In some cases, the practical has been designed so that only two or three cells are relevant.