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The role of practical work in the teaching and learning of science

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1 Introduction

The purpose of this paper is to explore and discuss the role of practical work in the teaching and learning of science at school level. It may be useful, however, to begin with some general remarks about science and science education, to lay out a framework for the discussion later in the paper.

First, and most fundamentally, we might ask: what is science, and what are its characteristics? The word 'science' is variously used in ordinary discourse in English to refer to a *product* (a body of knowledge), to a *process* (a way of conducting enquiry) and to an *enterprise* (the institutionalised pursuit of knowledge of the material world[1]). The distinctive characteristic of scientific knowledge is that it provides material explanations for the behaviour of the material world, that is, explanations in terms of the entities that make up that world and their properties. Through its choice of questions to address and the kinds of answers to accept, its methods of enquiry, and its procedures for testing and scrutinising knowledge claims, the scientific community has succeeded in building up a body of knowledge which is consensually accepted by that community and often also beyond it. Whilst this is always open to revision, its core elements are stable and beyond reasonable doubt. We value science (as a product, as an enquiry process, and as a social institution) because of its success in explaining phenomena in elegant and parsimonious ways, which are intellectually satisfying and which often facilitate the purposeful manipulation of objects, materials and events.

The aims of science education might then be summarised as:

- to help students to gain an understanding of as much of the established body of scientific knowledge as is appropriate to their needs, interests and capacities;
- to develop students' understanding of the methods by which this knowledge has been gained, and our grounds for confidence in it (knowledge *about* science).

The second of these is often referred to as 'understanding the nature of science', and encompasses elements of science both as an enquiry process and as a social enterprise. It includes an understanding of how scientific enquiry is conducted, of the different kinds of knowledge claims that scientists make, of the forms of reasoning that scientists use to link data and explanation, and of the role of the scientific community in checking and scrutinising knowledge claims. The two aims are closely inter-related. Indeed the second could be said to be entailed by the first: to claim to *know* something, it is not enough simply to believe it to be the case, but also necessary to have adequate evidence to support the claim (or at least to know what Norris (1992) terms 'the general shape that a justification would have to take' (p. 216)). In other words, you have to be able to say not only *that* you think it is the case, but also *why*.

Additional reasons have been put forward by science educators for emphasising knowledge *about* science. First, a better understanding of the structure of scientific knowledge and the forms of argumentation used by scientists may help students to learn science content. Second, citizens in a modern society need some understanding of the nature of scientific knowledge in order to evaluate claims that may affect their everyday decisions (e.g. about health, diet, energy resource use) and to reach

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[1] 'World' here should be interpreted broadly; the subject matter of science is the material universe. 'Material' includes living matter.

informed views on matters of public policy (e.g. genetic therapies, methods of electricity generation). Third, the characteristics of science as ‘a way of knowing’, and its ‘institutional norms’ of universalism, communalism, disinterestedness and organised scepticism (Merton, 1942), are of cultural (and perhaps moral) significance and value. These rationales reflect elements of two distinct perspectives which Irwin (1995) has termed the ‘enlightenment perspective’ and the ‘critical perspective’ and which, he suggests, underpin the concerns of various individuals and groups to improve scientific literacy and public understanding of science.

Whilst the two aims of science education identified above are closely inter-related, there is also one quite significant difference between them. The first might be stated as bringing students’ understandings closer to those of the scientific community. But it is rather harder to say whose ideas *about* science we wish to bring students’ understandings closer to. Unlike scientific knowledge, where there is consensus about core knowledge claims, there is rather less agreement about the characteristic features of scientific enquiry and scientific reasoning. In one sense, professional scientists clearly know more ‘about science’ than any other group, but their knowledge is often largely tacit – ‘knowledge in action’ rather than declarative, propositional knowledge. The eminent philosopher of science, Imre Lakatos, once memorably commented of scientists’ explicit knowledge of their practices that ‘most scientists tend to understand little more *about* science than fish about hydrodynamics’ (Lakatos, 1970: 148). But the views of philosophers of science also differ, as do those of science educators, certainly at the level of detail and perhaps more fundamentally. Furthermore, the questions that drive enquiry, and the methods of enquiry commonly used, vary across the sciences – so that generalisations about ‘the nature of science’ are rarely persuasive, and are often open to rather obvious objections. In thinking about this second aim of the school science curriculum, and the role of practical work in achieving it, it may be important to be clear as to whether we wish to promote a tacit ‘knowledge-in-action’ of science, or a more explicit, reflective and declarative knowledge.

It is also important to distinguish, and keep in mind, that the school science curriculum in most countries has two distinct purposes. First, it aims to provide every young person with sufficient understanding of science to participate confidently and effectively in the modern world – a ‘scientific literacy’ aim. Second, advanced societies require a steady supply of new recruits to jobs requiring more detailed scientific knowledge and expertise; school science provides the foundations for more advanced study leading to such jobs. These two purposes may lead to different criteria for selection of curriculum content, to different emphases, and (in the particular context of this paper) to different rationales for the use of practical work.

In this paper, I am using the term ‘practical work’ to refer to any teaching and learning activity which at some point involves the students in observing or manipulating the objects and materials they are studying. I use the term ‘practical work’ in preference to ‘laboratory work’ because location is not a critical feature in characterising this kind of activity. The observation or manipulation of objects might take place in a school laboratory, but could also occur in an out-of-school setting, such as the student’s home or in the field (e.g. when studying aspects of biology or Earth science). I also prefer not to use the term ‘experiment’ (or ‘experimental work’) as a general label, as this is often used to mean the testing of a prior hypothesis. Whilst some practical work is of this form, other examples are not.

2 Science as product and process – an essential tension?

The close interdependence of the two main aims of science education identified above – improving students' scientific knowledge *and* their knowledge of science as a form of enquiry – has led many science educators to argue that science education should combine and integrate them into a 'seamless' whole. The idea is that students are taught to carry out their own scientific enquiries and so acquire scientific knowledge for themselves. Clearly practical work has a central role in any such vision of science education.

In the UK, the idea of 'the pupil as scientist' underpinned the influential Nuffield Science Projects in the 1960s, which initiated a period of science curriculum innovation and reform that has continued to the present day. Though less prominent in subsequent developments, it has remained an influential notion in the UK and elsewhere. It is not difficult to see why it is attractive to science educators. Encouraging students to pursue their own enquiries taps into their natural curiosity. Finding things out for yourself, through your own efforts, seems natural and developmental, rather than coercive, and may also help you to remember them better. It seems to offer a way of holding up evidence, rather than authority, as the grounds for accepting knowledge. It is enabling, rather than dismissive, of the individual's ability, and right, to pursue knowledge and understanding for her/himself. Indeed one of the great cultural claims of science is its potential as a liberating force – that the individual can and may, though his or her own interaction with the natural world, challenge established tradition or prejudice, by confronting it with evidence. An enquiry-based approach may also encourage students to be more independent and self-reliant. In this way it supports general educational goals such as the development of individuals' capacity for purposeful, autonomous action in the world.

As regards knowledge *about* science, the enquiry-based approach often aims for a largely tacit understanding. As a result, it is difficult to assess how successful it is, as the outcomes are rather imprecise and difficult to measure. Are students becoming better enquirers or not? And how do we claim to know? As a method of teaching established scientific knowledge, however, the enquiry-based approach runs into significant difficulties in practice. These are of three kinds. First, students, because of their inexperience, or the quality of the equipment provided, or the amount of time available, often make observations or measurements which are incomplete, or incorrect, or insufficiently accurate or precise. As a result, the data they collect are not consistent with the intended conclusion. Second, when students do collect data that are good enough for the purpose in hand, they are often unable to draw the intended conclusion from them. The problem lies in the relationship between data and explanation. Ideas and explanations, even at the level of spotting correlations within a data set, do not simply 'emerge' from data. Rather they are conjectures, thought up imaginatively and creatively to account for the data. It is all too easy for the teacher, or science educator, who already knows the accepted explanations, to underestimate the difficulty of this step. From the point of view of the learner, who does not know the explanation, it is often far from obvious. To give one very simple example, students observing the pattern of iron filings around a bar magnet are unlikely to 'see' anything resembling lines of force until they have been shown this representation by the teacher (Gott and Welford, 1987). The lines are not *in* the data, but are a useful explanatory construct that can be imposed upon the data. A third, and more practical, difficulty with the enquiry approach to teaching scientific knowledge is that students know the teacher knows the answer, even if they themselves do not. As a result, they typically look to the teacher to tell them if what they saw is what was 'supposed to happen', and to confirm that their data are 'right' (Driver, 1975; Atkinson and Delamont, 1976; Wellington, 1981). They recognise that they are playing a social 'game' and not engaging in genuine 'discovery of knowledge'.

The underlying issue here is essentially an epistemological one. 'Discovery learning' is based on an empiricist view of science and an inductive view of the 'scientific method'. This is the view that all knowledge of the world arises from observation and that generalisations and explanations can be relied upon because they are supported by, and arise out of, a body of observations. This, however, does not take account of the influence of prior ideas and theories on the act of observation, both in terms of what we judge relevant to observe and on the observations we actually make (the so-called 'theory-ladenness' of observation (Hanson, 1958)). Also, as Popper (1959) pointed out, no number of positive observations can ever prove that a generalisation or explanation is correct, but one discrepant observation can, logically, indicate that it is incorrect. So a basis in accumulated observations does not of itself guarantee that a generalisation or explanation is correct. As a result of these and other similar critiques, most mainstream philosophers of science have moved away from an inductive view of science towards a more hypothetico-deductive one, which recognises the clear distinction between data and explanations. Figure 1 (based on Giere, 1991) summarises this view. By observation and measurement we can collect data on the 'real world'. Alongside this, we may conjecture explanations for the behaviour of this real world. From these, we may be able to deduce some specific predictions – which we can then compare with our data. If these are in agreement, they increase our confidence in the match between the explanation and the real world. If they disagree, they may lead us to question the explanation (or, of course, the specific predictions made from it, or the quality of the data). From an educational point of view, it is the clear separation of data and explanation – and the recognition that there is no direct route from data to explanation – that is the most useful insight.

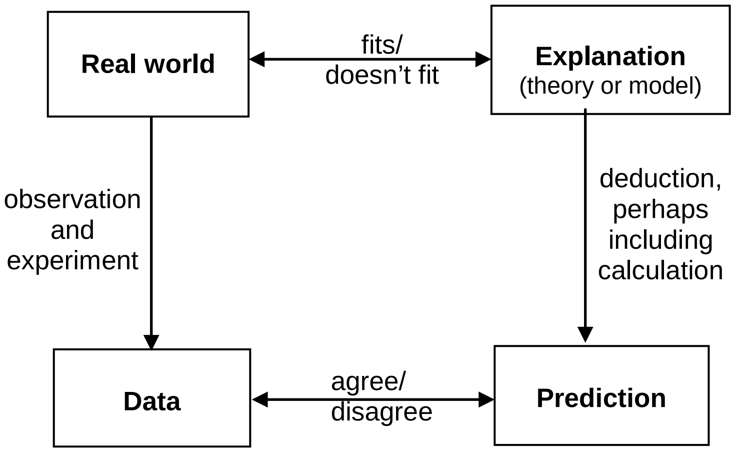

Figure 1 A model of scientific reasoning (based on Giere, 1991)

Although the dominant epistemological view amongst science educators has gradually shifted, over the past four decades, away from an inductive and towards a hypothetico-deductive view, the vision of a form of science education which integrates content and process has persisted; curricula and policy documents continue to portray practical activities as vehicles for developing understanding of both science content and enquiry procedure, without any explicit indication that *different kinds* of practical task might be needed for each aim. Thompson and Zeuli (1999) argue that such a vision is implicit in the recent standards-based reforms in the USA. This, they suggest[2], sees:

> the classroom as a scientific .. community governed by roughly the same norms of argument and evidence as govern discourse within communities of scholars in the discipline [itself]. Classrooms are scientific .. communities writ small. Science .. education reformers portray effective classrooms as small communities that adopt scientific … modes of communication and other conventions to help them struggle with challenging problems, thus developing systems of shared knowledge that gradually evolve in the direction of the knowledge held by communities of scholars in the discipline. (p. 347)

This does not assume that students will ‘re-discover’ the concepts and ideas of science for themselves, if suitably guided. Rather:

> At key points in the discussion, the teacher may present current scientific accounts of the phenomenon under study, but such presentations should come as answers to questions or solutions to problems that students are actively puzzling over – thinking about – not as answers to questions they have never asked, about phenomena they have never wondered about. (Thompson and Zeuli, 1999: 347-8)

The underlying assumption, as Thompson and Zeuli go on to point out, is that students will gradually construct not only their own understandings of scientific ideas, but will also learn how to carry out for themselves some version of the thinking processes that scientists use. Indeed, for some science educators, the aim is that students develop not only tacit ‘knowledge-in-action’ that enables them to conduct an enquiry ‘scientifically’, but also explicit, declarative understandings of the logic of scientific enquiry and of the nature of scientific knowledge.

In practice, however, there is a significant and quite fundamental tension between the aim of communicating elements of a body of received knowledge and the wish to convey messages about the methods of enquiry used to establish that knowledge in the first place. This can become particularly apparent in the context of practical work. Imagine a school class in which the students are carefully heating a previously weighed sample of magnesium ribbon in a crucible in order to oxidise it. They re-weigh the crucible and contents at the end. Several groups in the class record a weight that is the same as, or less than, the original weight. What is the teacher to do? The same question might be posed about a class in which some students get a negative test result for starch in the leaves of a plant that has been in the light for several days, or where some students record values of electric current that are different at points around a series circuit. In practice, the teacher is likely first to appeal to the norm within the class: what did *most* students find? The data collected by the others will then be accounted for using ideas like ‘experimental error’, perhaps due to poor equipment or lack of expertise. If no student groups got the intended results, the problem is more acute. Rarely, the teacher may propose that the class should repeat the whole exercise. But that is in itself an acknowledgement that what has been observed is not ‘what should have happened’. Additional information, not derived from the data collected, is being brought to bear on the situation and used to justify decisions and actions. Yet this typically sits alongside a rhetoric of data as the foundation of, and warrant for, our scientific knowledge – and the inconsistency is typically disregarded (or not even noticed). I do not want to imply that I think these typical teacher responses are inappropriate. The alternative – of taking the actual data

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[2] I should perhaps make clear that Thompson and Zeuli are not here expressing their own view, but rather summarising the view they think is implicit in other writings and initiatives.

collected as the warrant for subsequent views and ideas – leads potentially to confusion and is often not viable or sensible.

We should not underestimate the depth of the difficulty here. Science is, quintessentially, a body of consensually accepted knowledge about the natural world, so teaching science is inevitably a goal-directed activity. The aim is not simply to help students develop their understanding of the natural world, but to develop it *in a particular direction* – to bring their ideas and understandings closer to those of the scientific community. Learning science is an induction into a particular view of the world. As a consequence, 'at the school level, … the acquisition of scientific knowledge is inescapably tinged with dogmatism' (Layton, 1973:176; see also Kuhn, 1962, 1963). Many students sense this 'dogmatic' character of science education, and find it off-putting. Many science teachers and educators are also somewhat uneasy about it. The eminent biology educator Joseph Schwab (1962) castigated it as teaching 'a rhetoric of conclusions'. Yet we cannot deny that many fundamental science ideas are so well-established that disputing or questioning them, or encouraging students to develop their own 'alternatives', is unproductive. Students' 'alternative' ideas may be useful *during* the learning process, but more doubtfully so as endpoints. Integrating what we want to say about scientific enquiry with the closed and consensual character of core scientific knowledge must surely involve acknowledging that core scientific knowledge *is* consensually agreed – and attempting to explain how it became so. In other words, the 'closure' of scientific disputes in the past, and the processes by which consensus was reached on some of the core ideas of science, needs to become part of the curriculum, and not remain hidden in the background. The paradox that science celebrates a questioning, critical stance towards knowledge claims, but has also created 'islands' of consensually agreed knowledge which it is not productive to question, needs first to be more clearly and generally recognised.

Writing about this paradox, and the tension it creates for science education, Layton (1973) concludes that:

> it is difficult to see how both objectives, an understanding of the mature concepts and theories of science and an understanding of the processes by which scientific knowledge grows, can be achieved simultaneously. … The problem of reconciling these objectives in school science teaching has been considerably underestimated. (pp. 176-7)

His view is amply borne out by experience. There are no obvious examples, anywhere in the world, of a form of science education like that sketched by Thompson and Zeuli above being successfully implemented in a national education system. At best, educators may be able to point to isolated instances, where a particularly insightful and gifted teacher has succeeded in sustaining something of this sort for a period of time with some groups of learners. Layton's suggestion that we 'attend to process as a separate objective, important in its own right, alongside content' (Layton, 1973:176) is perhaps a more defensible, and also a more practicable, way of dealing with the tension.

It is also the approach that this paper will take. In the next section (section 3), I will discuss the role of practical work in the development of students' scientific knowledge. Then section 4 will consider its role in developing students' understanding of scientific enquiry and of the nature of science.

3 The role of practical work in the teaching and learning of science content (scientific knowledge)

3.1 Learning science: a constructivist view

The argument developed in the previous section, in particular the view that much of the scientific knowledge we want to teach in school science is consensually agreed and beyond reasonable dispute, might be read as implying a 'transmission' view of teaching and learning – that the aim is to 'transfer' the knowledge initially in the teacher's mind into those of the students. But this does not follow. Where the teaching of abstract ideas is involved, transmission simply does not work. The learner must play an active role in 'taking on' the new knowledge. He or she has to 'make sense' of the experiences and discourse of the science class, and use it to 'construct meaning'. In this essentially constructivist view of learning, however, the knowledge that we want the students to construct is already known to the teacher throughout. The teaching laboratory is therefore very different from the research laboratory, as Newman (1982) points out.

> The young child is often thought of as a little scientist exploring the world and discovering the principles of its operation. We often forget that while the scientist is working on the border of human knowledge and is finding out things that nobody yet knows, the child is finding out precisely what everybody already knows. (p. 26)

Learning science at the school level is not the discovery or construction of ideas that are new and unknown. Rather it is making what others already know your own[3]. The difference, from a cognitive perspective, is like that between solving a puzzle and having the solution explained to you by someone who already knows it. The first might involve pursuing several lines of reasoning, and there is no guarantee of eventual success, whereas the second is convergent and with an assured outcome. But there is still cognitive work to be done to grasp it, so as to be able to explain it in turn to someone else, or to apply it to new situations.

An implication of this viewpoint is that practical tasks to develop students' scientific knowledge should be seen, and judged, as acts of communication and not as opportunities for enquiry. The primary criterion which a practical task of this sort should satisfy is that it is an effective means of communicating the idea(s) it is intended to convey. How, we might ask, and how effectively, does it augment other forms of communication (verbal, graphical, pictorial, symbolic) that teachers might use. By 'communication' here, I do not simply means acts of 'telling', but the whole range of activities that a teacher plans to encourage and support students as they attempt to construct personal meanings that are more closely aligned with the accepted scientific view.

3.2 Why practical work is essential for developing students' scientific knowledge

Given that the subject matter of science is the material world, it seems natural, and rather obvious, that learning science should involve seeing, handling and manipulating real objects and materials, and that teaching science will involve acts of 'showing' as well as

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[3] Goethe puts this understanding of 'constructivism' rather nicely in *Faust* when he writes: 'Was du ererbt von deinem Vätern hast, Erwirb es, um es zu besitzen.' (Part I, Scene 1, Night, lines 682-3): (What you have inherited from your forebears, make it your own it if you would possess it.)

of ‘telling’. But what exactly is the role of practical experiences, how do they aid understanding, and are they essential?

The central question about knowledge and cognition is: how, exactly, do we (humans) get the world inside our heads? In other words, how do we construct representations of the external world which enable us to live successfully in it, and act successfully upon it when we need or wish to? One influential answer to this is provided by the work of Jean Piaget. Piaget argues that we construct increasingly sophisticated and powerful representations of the world by acting on it in the light of our current understandings, and modifying these in the light of the data this generates. Through action on the world, we generate sensory data which can either be *assimilated* into existing schemas or require that these be changed to *accommodate* the new data, in order to re-establish *equilibrium* between the internal and external realities. Through such action, we construct a view of the objects that exist in the world, what they are made of and what can be made from them, what they can do and what can be done to them. If Piaget is correct, then practical experience of observing and (even more important) intervening in the world is essential for understanding.

The account above may tend to make understanding seem a personal matter – the individual constructing his/her own representations of the world though action on it. Indeed Piaget’s view has been criticised on these grounds. In practice, the representations we construct are tested out not only through action, but also through interpersonal interaction. We talk about how we see things. We bounce our ideas off others, and have them bounce theirs off us. Our ideas are consolidated where they agree with others’ and challenged where they differ. Through social interaction, our ideas are modified and refined – and so are shaped towards a shared set that makes discourse and collaborative action possible.

One word of caution is, however, required. This might provide an account of how we acquire commonsense understandings of the natural world, including fundamental ideas such as the very idea of an ‘object’ itself, of cause and effect, of conservation of number, substance, weight, volume, of classification and groupings and their inter-relations. These basic ideas are regularly tested against experience in everyday situations; they are clearly functional in dealing with these and so are reinforced. Scientific knowledge, however, has been developed for more specific and specialised purposes. Many of its explanations are counter-intuitive and not supported by everyday experience (at least not until you have learned to ‘read’ that experience in very specific ways). The processes by which these ideas are first arrived at, and by which they are subsequently supported, are more specialised and particular – and depend not only on practical experience but also on culturally mediated interpretations of that experience. The implications of this are explored further in the next sub-section.

3.3 Practical work involves action and reflection

In section 1 above, I defined ‘practical work’ as any teaching and learning activity which involves at some point the students in observing or manipulating real objects and materials. It is clear from the discussion above, and also widely recognised by science educators, that much of the learning associated with a practical activity takes place through the process of talking about the observations and measurements that have been made, and what they might mean, both with other learners in the class and with the teacher. So a typical practical activity will be followed by a period of discussion of the observations and measurements made, of patterns in them (such as similarities, differences, correlations and trends), and of how they might be interpreted and explained. This is so closely linked to the preceding practical activity that it does not make much sense to separate them and regard them as two distinct teaching and learning activities – even if, for practical reasons, the discussion takes place in a subsequent lesson, or in a different place (a classroom rather than a laboratory). Instead, we should see the whole activity – the data collection phase and the data interpretation phase – as constituting a practical task.

Following this line of reasoning, it then follows that, cognitively, there is nothing uniquely distinctive about practical work which marks it off from other kinds of science learning activity. The same kind of discussion as might follow a practical activity can take place in a lesson where there is no data collection because the phenomena which the teacher wants to explore with the class are ones that s/he can assume are already well-known to pupils from their everyday experience. For example, imagine a teacher beginning a lesson on the idea of inertia in Newtonian mechanics. S/he might ask the class if they have ever found themselves having to stand in a bus or train, because it was crowded – and to say what they remember happening (and feeling) as the vehicle started off, or when it braked. From their shared experiences, s/he might then draw out the idea that objects are somewhat resistant to changes in their motion. There has been no practical work in the sense of in-class data collection. But the cognitive processes involved are the same as when data collected by the students are discussed and reviewed. The aim is to draw students' attention to a phenomenon, to isolate parts of it for particular scrutiny, and to talk towards a way of thinking about it. The aim is to develop a link between an observation and a way of thinking about it – between the world and a mental representation of the world. The teacher is, in effect, saying 'see it my way' (Ogborn et al., 1996). This is at the heart of all science learning – and practical work plays a critical role in it. We use practical work in science classes when students are unlikely to have observed the phenomenon we are interested in, or to have observed it in sufficient detail, in their everyday lives. In such situations, it is essential and irreplaceable.

3.4 Making links between two domains of knowledge

As the preceding sub-section has argued, the role of practical work in the teaching and learning of science content is to help students make links between two 'domains' of knowledge: the domain of objects and observable properties and events on the one hand, and the domain of ideas on the other (Figure 2) (Millar et al., 2002).

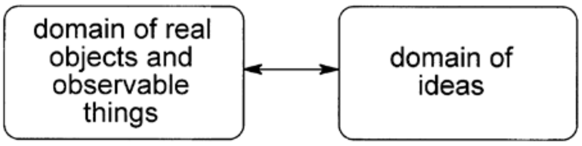

Figure 2 Practical work: linking two domains of knowledge

How this then plays itself out in practice depends on the intended learning objectives of the task. Table 1 shows one way of classifying the objectives of a practical task intended to improve students' scientific knowledge.

To help students to:	
1	identify objects and phenomena and become familiar with them
2	learn a fact (or facts)
3	learn a concept
4	learn a relationship
5	learn a theory/model

Table 1 Possible intended learning outcomes (learning objectives) of a practical task intended to improve students' scientific knowledge (from Millar et al., 2002)

In the first category are practical tasks whose main aim is to enable students to observe an object or material or event or phenomenon, to note some aspects of it, and perhaps be able later to recall these. This is often a necessary precursor for one or more of the other objectives listed. A 'fact' (objective 2) simply means a 'quickly decidable sentence' (Feyerabend, cited in Maxwell, 1962: 13), in other words an observation statement that can be readily agreed, and is expressed in everyday language, such as that common salt dissolves in water but chalk does not, or that pure water boils at 100^{o}C. Examples of concepts (objective 3) that might be developed using practical work are electric current, resistance and potential difference. A 'relationship' (objective 4) means a correlation or trend – that is, a pattern linking two or more observable properties or characteristics. This might be between observable features of the situation, but could also involve abstractions (for example, modelling situations in terms of variables, relationships involving conceptual terms). Whilst it can be argued that all practical work involves both domains in Figure 2, the domain of ideas plays a more significant role in practical work with learning objectives 3, 4 and 5. For all objectives, but most particularly for objectives 3-5, the qualification implied by the introduction 'to *help* students learn' is important. It is unlikely that a student would grasp a new scientific concept or understand a theory or model as a result of any single practical task, however well designed. Coming to an understanding of these is more likely to be a gradual process of acquiring deeper and more extended understanding of an abstract idea or set of ideas. Whilst a practical task may contribute usefully to this, it will only be part of a broader teaching strategy.

Many science educators have, however, expressed significant doubts about the effectiveness of practical work, as it is currently used, for teaching scientific knowledge. Hodson (1991), for example, writes 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 … At the root of the problem is the unthinking use of laboratory work. (p. 176)

Woolnough and Allsop (1985) and Osborne (1993) express similar doubts about the contribution of practical work to students' science learning. The focus of these criticisms is mainly on practical tasks with learning objectives 3-5 in Table 1. For tasks with objectives 1 and 2, where the emphasis is on the domain of objects and observables, evidence suggests that these are as effective as many other forms of instruction. Students *do* remember observable aspects of practical tasks, often many months or even years later, particularly when the event is a striking one (such as seeing a piece of sodium put into water, or three projected beams of red, green and blue light overlapping on a screen to produce a white area). Even so, many practical tasks of this type might be made more effective by designing them to stimulate the students' thinking *before* they make any observations. For example, rather than simply recording the speed of a falling object after dropping different distances, students might be asked: 'does a falling object quickly reach a steady speed and then fall at that speed, or does it keeping speeding up during its fall?' Whilst exploring the effect of forces on motion, students might be asked: 'when you kick a ball along the ground, does it continue to speed up for a while after it leaves contact with your foot?' A teacher with whom I have recently worked stimulated animated discussion in one of her classes by asking students to predict the reading on a top-pan balance when a stone (and, in other similar examples, a wood block, some sand, and some sugar) is moved from a position beside a beaker of water and placed in it (Figure 3) – before going on to check this out by making measurements.

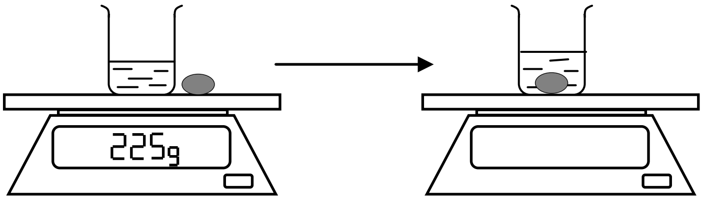

Figure 3 **A practical task on conservation of mass (weight)**

Many students do have incorrect expectations about matters of fact – and practical work can challenge these. It may do so more effectively if the students' predictions have been declared in advance, and when the practical task can fairly unequivocally endorse one prediction and refute another. The predict-observe structure also makes the practical task more purposeful. Otherwise a practical task designed to enable the students to observe an object or phenomenon can easily become rather dull and uninspiring, unless the event itself is a particularly memorable one. Predictions, of course, are only valuable if they are more than mere guesses, and are derived from ideas about the situation.

Turning then to practical tasks with objectives 3-5 in Table 1 above. These are, I think, the real target of the critiques of practical work cited above. Here both domains of knowledge are strongly involved. The commonest weakness of practical tasks of this sort is taking insufficient account of the need to help student make links between the two domains. The cognitive challenge for the students is often underestimated. Teachers often appear unaware that these tasks are cognitively much more demanding than those with learning objectives 1 and 2. The failure to recognise this may have its roots in the empiricist/inductive view of science discussed in section 2 above: the belief that ideas will 'emerge' automatically from the event itself, if students work carefully enough. In practice this rarely happens.

Despite the inherent difficulty of helping students to make links between observations and ideas, and the weakness of much current practice, practical work is not an 'optional extra' in developing students' understanding of scientific concepts and explanations (objectives 3-5 in Table 1), but a necessary component. The reason lies in Piaget's insight that it is by *acting on* the world that our ideas about it are formed and develop. Students, therefore, need to have experiences of acting on the world, in the light of a theory or model, and seeing the outcomes. Only in this way can they come to an understanding of that theory or model. For example, when students measure the temperature over a period of time of water in beakers with and without insulating jackets, they are (we intend) coming to see this phenomenon in terms of a theoretical model, of energy moving spontaneously from regions of higher to lower temperature, at a rate which depends on the materials in between. Their actions make sense within the framework provided by this model; acting in the light of it, and talking about it using the terms and ideas in the model, are crucial for establishing and consolidating this way of seeing the world. Similarly, when students measure the electric current at different points in a circuit with parallel branches, they are (we intend) coming to imagine the circuit in terms of current as a flow of something (charge) which is not used up as it goes and adds (or splits) at junctions.

Where such tasks fail as learning events, the reason is often that the domain of ideas has been ignored in the task design. The practical tasks of this sort which are most effective are those which have explicit strategies for getting students to think about the explanatory ideas involved, so that they do not focus only on the observables. The predict-observe-explain (POE) structure (White and Gunstone, 1992) discussed earlier is particularly useful, if the students already have enough theoretical understanding of the phenomenon in question to make testable predictions. In a POE task, students are first asked to predict what they would expect to happen in a given situation and to write this down, then to carry out the task and make some observations, and finally to explain what they have observed (which may or may not be what they predicted). Other strategies can also be used. Tiberghien (1996), for example, describes a teaching sequence for introducing ideas about energy transfer at secondary school level. This involves presenting students with what she terms the ‘seed’ of a model, in this case the outline of a way of representing simple processes in energy terms. Students are then asked to look at a number of other energy transfer processes (batteries lighting bulbs and lifting weights, and so on) and to represent these using the same ideas and conventions. The fact that students find this quite difficult at first – to a greater extent than many teachers anticipate – is an indication of the cognitive demand. Another strategy is to present and discuss an analogy to which observations and measurements can be directly related. For example, in teaching about the behaviour of simple electric circuits, students might be asked explicitly to relate their observations to a given analogy of circuit behaviour, noting where these agree with what the analogy would lead you to expect, and where they diverge.

Strategies for improving practical work intended to develop students’ scientific knowledge have a common aim – to make the students *think* as well as *act*. Effective tasks are those where students are not only ‘hands on’ but also ‘minds on’ (Duckworth, 1990). Increasing their prevalence requires first that teachers become more aware that making links between the domain of objects and observables and the domain of ideas is demanding, and then helping them to design practical tasks which take this demand more explicitly and fully into account – tasks which ‘scaffold’ students’ efforts to make these links. This in turn requires that teachers analyse more carefully the objectives of the practical tasks they undertake, and become more aware of the cognitive challenge for their students. The starting point for improving practical work is therefore to help teachers become much clearer than many are at present about the learning objectives of the practical tasks they use.

3.5 Alternatives to practical work

To what extent, it might be asked, could practical work to develop students' scientific knowledge be replaced by non-practical learning activities, such as video-recordings of real objects and events, or computer simulations? For learning objectives 1-2 in Table 1 above, their contribution is limited. Video-recordings of events and processes *can* be used to let students see events that could not be produced in the school laboratory, or to view events several times in order to look closely at different aspects of them. But they cannot wholly replace first hand practical experience. The fundamental reason is that a real event contains more information than any representation of it. All representations (video recordings, photographs, diagrams, verbal accounts) are selective, to a greater or lesser extent[4]. They communicate some aspects of the event but not others. A student will get more complete data on what happens when a piece of magnesium is put into dilute hydrochloric acid, or when two solutions are added and a solid precipitate is formed (to take just two examples), by observing the real thing, than they could obtain from observing a representation. And they may gain still more by doing it, where there are kinaesthetic aspects of the learning, and because of the greater attention we pay when we carry out actions ourselves. The role of simulations in relation to learning objectives 1 and 2 is even more dubious. A simulation cannot, logically, provide grounds for knowledge of the world. It might, however, provide a useful preparation for an observation of a real phenomenon, by directing the students' attention to specific features of the real event.

If we turn to learning objectives 3-5 in Table 1, non-practical approaches may have more to offer. Video materials can juxtapose images of real events and processes with theoretical ideas and constructs, for example showing a chemical reaction alongside an atomic-level representation of the process, or the process of imaging by a convex lens alongside a ray diagram (Goldberg and Bendall, 1992). Similarly, well-designed computer-based teaching materials, including simulations, animations and other kinds of modelling activity, can also be very useful in helping students to operate in the domain of ideas. For example, a software tool under development by the Gatsby Science Enhancement Project illustrates a way of helping students link observations of simple laboratory events to a model of energy transfers (http://www.sep.org.uk/energy.htm#).

3.6 Effective practical work to develop students' scientific knowledge

The idea of 'effective' practical work has come into the preceding discussion at several points. It may be useful to clarify what we mean by the term 'effectiveness'. Figure 4 shows four stages in the development and implementation of a practical task. 'Effectiveness' usually refers to the link labelled (2): do students learn what we intended them to learn? But in order to be effective in this sense, a task must first be effective at level (1), that is, the students must do (and be able to do) the things the task designer intended them to do. A common criticism of practical work in the teaching laboratory is that it becomes 'recipe following', with the students often not thinking about *why* they are doing what they are doing. The provision of detailed 'recipes' is a reflection of the teacher's (or task designer's) concern with effectiveness at level (1). Whilst this is a necessary condition for effectiveness at level (2), it is not a sufficient one. As discussed

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[4] In some situations, this selectivity is an advantage, as I will argue later in the case of teaching students about some aspects of scientific enquiry.

above, explicit design features are often required to help students use their observations to draw the intended conclusions.

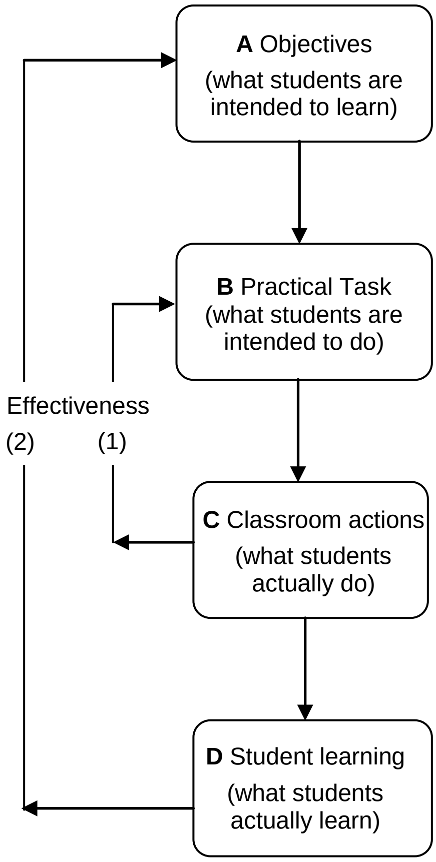

Figure 4 The process of developing and implementing a practical task (from Millar et al., 2002)

As the task design follows from the learning objectives, a first characteristic of effective practical tasks is that the learning objectives are clear. Second, a practical task should have a *limited number* of intended learning outcomes. It is easy for practical tasks to become too complex, so that students get lost in the 'noise' of the bench. If a specific skill is necessary for a task, students need to be competent in this beforehand, or it may get in the way of the intended learning. (For example, if we want students to measure electric current before and after a junction point in a circuit with parallel branches, they must first be competent in building a circuit to match a given diagram, and in using an ammeter to measure current. It is better to establish these competencies in advance than to believe they can be picked up in the course of a more complex activity.) Whilst computer-based instrumentation (such as data-logging probes and software) can enhance some practical activities (for example, by enabling graphs to be generated as the primary data format), it can also add additional layers of opacity and increase the physical and cognitive 'clutter'. Its effectiveness depends on *how* it is used, not *that* it is used. Conversely, many examples of effective practical work use cheap and readily available equipment. Students can be more effectively 'minds on' as well as 'hands on' when they feel they understand how the equipment they are using works.

And, in the case of practical tasks which require the students to make links between the domain of objects and observables and the domain of ideas, effective tasks are those which use explicit and planned methods of 'scaffolding' the students' thinking, to direct and channel their reasoning along productive lines.

4 The role of practical work in teaching and learning about the nature of science

4.1 The purposes of school science

Before discussing the role of practical work in developing students' understanding of scientific enquiry and the nature of scientific knowledge, I want to return to an issue raised in section 1 of this paper. This is that school science has two distinct purposes: to develop the 'scientific literacy' of all students as a preparation for active citizenship; and to provide the foundation for further study of science for those students who may wish to follow careers that require this. For both these purposes, I would argue, developing students' scientific knowledge is a necessary aim. The two purposes may lead to different choices about the areas of knowledge which should have priority, and the depth of treatment required. But whatever choices are made, the issues that arise in developing students' knowledge will be similar. So the discussion in section 3 above applies equally to both purposes.

When we turn, however, to thinking about the curricular aim of developing students' understanding of scientific enquiry and the nature of scientific knowledge, the differences between the two purposes of science education may be greater. In courses whose purpose is to enhance students' scientific literacy (as distinct from the pre-professional training of future scientists), practical work is a means to an end, rather than an end in itself. Citizens do not (*qua* citizen) undertake scientific enquiry (some may engage occasionally in systematic enquiry – which is not the same thing). So they do not require to become proficient in it. They are *consumers* of scientific knowledge, not *producers* of it. To become more intelligent consumers, they may benefit from some experiences of practical work, but the aims need to centre on developing the knowledge and understandings required to respond intelligently to scientific information as it is encountered in out-of-school contexts, rather than on the ability to conduct a practical investigation or enquiry for themselves. For such students, an explicit (declarative) understanding of the logic of scientific enquiry and of the nature of scientific knowledge (meta-knowledge *about* science) is, I would argue, more important than the tacit understandings which underpin actions and choices in carrying out a practical enquiry task. The latter may, however, be more important (indeed may even be regarded as of primary importance) for students who may wish to progress to more advanced study of science.

4.2 Projects and practical investigations

For much of the history of science education, it has been in effect assumed that students will pick up what they need to know *about* science as they acquire scientific knowledge. In that most practising scientists were taught science this way, it seems to be a successful method of developing, in that sub-group at least, adequate 'knowledge-in-action' of how to 'do science'. Many science courses and curricula, however, include activities whose primary aim is to develop students' understanding of scientific enquiry (and their ability to engage in it) and also, perhaps, their ideas about the nature of scientific knowledge. These often centre on practical work of a more extended and investigative character, where students have some freedom to choose equipment and methods and in to interpret their findings. Often the principal intended learning outcome is tacit knowledge of the processes of scientific enquiry expressed through practical capability (the ability to plan, design and carry out a scientific investigation), though the aim may also, to a greater or lesser extent, be to develop a more reflective, declarative knowledge of the nature of science.

There is some evidence that experience of carrying out extended practical projects can provide students with insights into scientific practice and can increase interest in science and motivation to continue its study (Jakeways, 1986; Woolnough, 1994). Examples of the successful use of extended projects are, however, mainly at upper secondary school level or above, where students are to some extent self-selected, teachers have (in general) better subject knowledge, and groups sizes are smaller. There are few examples of the successful implementation of extended practical projects or investigations as part of the science curriculum in the context of ‘mass education’, where large numbers of teachers and students are involved. Teachers find it difficult to devise or to help students to generate enough project ideas, year on year. It is easy for the activity to become routinised, and become something very different from what was originally envisaged when it was included in the curriculum.

This is very much the story of Attainment Target 1 ‘Scientific enquiry’ in the English national curriculum (DfEE/QCA, 1999). This lists some specific points that students should be taught, under the general heading of ‘investigative skills’. These are at a very general level, for example, that students ‘should be taught to use observations, measurements and other data to draw conclusions’ (p. 29). The way in which these are then interpreted and operationalised for the purposes of national examinations at age 16, however, has resulted in many teachers using one of a very small set of practical tasks from year to year, chosen to make it as easy as possible for their students to include those features for which the teacher can award marks. Without being explicitly told what to do, students are then coached and corralled through these activities so that they obtain as high marks as possible[5]. Also, the assessed investigations become almost the only investigations actually done. (For a fuller account of the rather dismal history of this curricular experiment, see Donnelly et al., 1996).

When investigative practical work is included in the science curriculum, it is also often criticised for portraying an inaccurate or incomplete image of scientific enquiry. In particular, the kinds of tasks which students undertake are often empirical investigations of relationships between variables. Whilst this is one important form of scientific enquiry, and highlights some important ideas about scientific (and logical) reasoning, focusing on it to the exclusion of other aspects of the scientific approach leads to distortion. The basic flaw in this image of scientific enquiry:

> is the apparent assumption that science is a sort of commonsensical activity. … There seems to be no explicit recognition of the powerful role of the conceptual frames of reference within which scientists and children operate and to which they are firmly bound. (Atkin, 1968: 9)

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[5] The fact that schools’ average scores are published nationally in the form of ‘league tables’ of school performance is a strong influence on these practices.

This criticism has also been levelled at the English national curriculum, which has sought to address it in its most recent revision (DfEE/QCA, 1999) by adding a strand, and some teaching targets, on ‘ideas and evidence in science’. It is too early to say with any certainty what impact this will have on practice. Overall, however, the introduction of investigative practical work in the English national curriculum has led to rather disappointing practices. In part, the problems can be traced to lack of clarity about the intended learning outcomes. The inclusion in the curriculum of investigative practical work stems from a rather broad and general, and somewhat romantic, view of its educational benefits. Doing a practical project is seen as ‘a good thing’. It is also seen as a means of escaping from ‘recipe following’, or ‘cookbook’, practical work. This is a laudable enough aim; following instructions, without thinking about what you are doing or why, is unlikely to lead to learning. Students who have been involved in deciding some of the features of the practical task they are engaged in (the question it addresses, the apparatus and equipment they will use, the data they will collect, how they will analyse and interpret these) are more likely to think about what they are doing and finding, and to learn from it. But without more specific targeting of learning outcomes, students often show disappointingly little improvement with age and experience in their performance of practical investigations.

One final word of caution about practical projects and investigations. It is important (again) to recognise the differences between the teaching laboratory and the research laboratory. Research scientists explore the unknown, seeking to add to public knowledge. They are committed to extending the boundaries of the known, and believe they are capable of doing so. Student investigations in the teaching laboratory are either of phenomena whose interpretation is well established and beyond serious question, or of local or particular phenomena of little wider, or theoretical, significance or interest. The tasks in which they are engaged are not, whatever some science educators’ rhetoric might imply, ‘authentic’, if by that we mean that they are closely similar to those undertaken by professional scientists. We might do better to recognise that *all* practical tasks in the teaching laboratory are simulations, that is, they model some aspects of professional scientific practice and not others. This can be a benefit as well as a constraint. We can choose the aspects we wish to model, provided we are clear enough about our intended learning objectives.

Finally, it is important to set all these issues concerning investigative practical work within the broader context discussed in section 4.1. The learning objectives pursued through investigative practical tasks are ones which are more obviously important for the minority of school students who may wish to continue to more advanced study in science, than for the majority who will not. Ordinary citizens do not need to be able to carry out such enquiries. Practical work of this sort has a role in science courses aimed at developing scientific literacy only insofar as it helps to develop insights into the nature of scientific knowledge claims that can help people assess the kinds of information they encounter in everyday life. For this purpose, an explicit and critically reflective understanding of the logic of enquiry and the nature of the knowledge produced may be more useful. This is discussed in the next sub-section.

4.3 *Teaching about the logic of scientific enquiry and the nature of scientific knowledge*

Developing students' understanding of the logic of scientific enquiry and the nature of scientific knowledge as a curriculum objective requires actions that go beyond developing students' ability to undertake open-ended practical investigations. At the very least, it requires some reflection on the investigative process, and on the nature of the knowledge produced, in the students' own investigations or in the work of professional scientists, or both. The inclusion of some history of science seems essential if issues of theory development and theory change are to be considered, as contemporary science at the 'cutting edge' is invariably too difficult for students to grasp the issues at stake or the evidence supporting or challenging different viewpoints.

To clarify the curricular implications of these aspirations, we need to probe more deeply into what is meant by 'an understanding of the nature of science' and try to make clear exactly what we would like students to understand. Whilst consensus about the nature of science is considerably weaker than about scientific knowledge itself, there is a core of ideas to which most would subscribe. These might be summarised as follows:

- all scientific knowledge is systematically informed by observational data;
- for data to become evidence, they must be interpreted within theoretical and practical traditions;
- interpretation is an open-ended and flexible process, so interpretations may legitimately differ, and the outcome is always essentially provisional;
- despite this, scientists have been able to reach consensus about data and its interpretation in certain areas of interest.

Unpacking this a little might then lead to the following learning objectives:

- an appreciation that all observation and measurement is inevitably subject to uncertainty (in other words, you can never be sure that you have made a 'true' observation or measurement) – and a knowledge of how to judge the extent of this and how to deal with it;
- the ability to model simple phenomena in terms of the effect of one or more independent variables on a dependent variable (and associated ideas about control of variables and 'experimental design' more generally);
- an understanding of the relationship between data and explanation, along the lines of Figure 1 above (in particular, an awareness that explanation is distinct from data, and cannot be simply deduced from it);
- some understanding of the role of the scientific community as a 'quality control' mechanism and of its 'institutional norms' (universalism, communalism, disinterestedness and organised scepticism) (Merton, 1942), and of the processes and reasoning that have led to the 'closure' of some past debates.

Practical work has an important role to play in this – though it cannot carry the whole load and must be used alongside other teaching approaches. More specifically, practical work is essential for giving students a 'feel' for the problematics of measurement, and an appreciation of the ever-presence of uncertainty (or measurement error). It is also an important tool for teaching about experimental design. Indeed research suggests that students design better investigations when they actually carry them out than when only asked to write a plan; feedback from experience improves design (APU, 1988: 100).

Practical work of this sort can, however, be made much more effective than it often is at present by more careful and detailed task design, starting (again) from greater clarity about the intended learning outcomes. If we want to highlight the problem of measurement uncertainty, and begin to explore ways of estimating it and dealing with it, then practical tasks need to be designed to focus students' attention on this issue. As with teaching science content, the task will only work if it triggers acting thinking on the students' part. So, for example, tasks which ask students which of two given objects or materials is heavier, denser, of higher resistance, or whatever, can stimulate much debate and argument, especially if examples are chosen that progressively challenge the limits of accuracy of the available measuring equipment. Similarly, students can learn important ideas about data interpretation from practical tasks that ask them to find out whether a given independent variable does or does not affect a dependent one (for example, does the mass on the end of a pendulum affect its time of swing?) Compared to showing that two variables co-vary, collecting good evidence that one variable has no effect on another is a considerable challenge, which can both reveal and help to develop student's ideas about data collection and interpretation (Kanari and Millar, 2004). Unless tasks are designed with specific, and progressively challenging, objectives in mind, the research evidence suggests that students' thinking about scientific enquiry advances little if at all. Many children by age 9 appear to grasp the idea of a 'fair test' – the need to vary only one thing at a time in order to find out how a specific factor affects the outcome – in the context of comparisons of cases. This does not, however, appear to develop smoothly into the ability to design well-planned investigations of the effect of two continuous variables, which many cannot manage confidently by age 16. A clearer and more detailed analysis by science educators of this knowledge domain is a necessary first step, to map its content and the inter-relations between key ideas, and to identify pathways along which students' understandings might be developed.

For teaching all these ideas about scientific enquiry, and in particular for teaching about the relationship of data and explanation and the role of the scientific community, non-practical methods are also needed. In the UK, the widely adopted teaching materials of the Cognitive Acceleration through Science Education (CASE) project (Adey et al., 1995) include explicit teaching of ideas about variables, control of variables and experimental design. Teachers using these see them as stimulating changes in students' ideas and understandings. Computer-based simulations may also help to reduce the 'noise' of the laboratory bench and focus attention on important aspects of experimental planning and data interpretation (Millar, 1999). Data interpretation tasks, including exercises like those used by researchers (for example, Kuhn et al., 1988; Koslowski, 1996), may be useful in probing and developing students' ideas about the relationships between data and explanation. Historical material on the emergence of consensus about some important scientific ideas and explanations may be needed to explore warrants for knowledge, and the role of the scientific community in establishing ideas as 'knowledge'. Computer-based tools (for example, Bell and Linn, 2000; Sandoval, 2003) can help to engage students more actively in thinking about issues of theory choice.

There is a tendency in science education writings and teachers' discourse, linked to the dominance within the international science education community of the 'critical perspective' on scientific literacy over the 'enlightenment perspective' (Irwin, 1995), to emphasise the provisional and revisable character of scientific knowledge. Yet the characteristic of science – the thing that makes it really distinctive – is not that it produces contested knowledge of the world. Many forms of intellectual activity can do that. What is distinctive about science is that it has, as a matter of fact, produced a few little islands of consensus – areas of knowledge where it no longer seems worthwhile disputing the accepted interpretation. Do any of us really believe, for example, that we can only claim that infectious diseases *may be* transmitted by micro-organisms, or question that water really *is* H_2O, or that the shape of a DNA molecule *is* a double helix? As part of the discussion of epistemological ideas, it may be important for students to have opportunities to explore in some depth a few examples of the process of arriving at consensus, of the closure of debates. It would clearly not be possible to do this for all of the science content we might wish to teach, but it may be valuable to do it for a few cases. Whilst this is unlikely to involve a great deal of practical work, it might provide the intellectual resources to resolve (or at least diminish) the tension discussed at some length earlier in this paper, between the messages implicit in practical work to support the teaching of scientific knowledge and the explicit ones we might wish to communicate about the nature of science.

5 Summary

It may be useful to end this paper by summarising briefly its main points about the role of practical work in science teaching and learning.

1. Practical work is an essential component of science teaching and learning, both for the aim of developing students' scientific knowledge and that of developing students' knowledge *about* science.

2. In thinking about the role of practical work, it is important to bear in mind the significant differences between the research laboratory and the teaching laboratory (or classroom); and between research scientists exploring the boundaries of the known and students trying to come to terms with already accepted knowledge.

3. Practical work which aims to develop students' scientific knowledge is best seen, and judged, as *communication* rather than as *enquiry*.

4. Practical work to develop students' scientific knowledge often requires students to make links between two domains of knowledge: the domain of objects and observables, and the domain of ideas. This kind of practical work is likely to be most effective when:
   - the learning objectives are clear, and relatively few in number for any given task;
   - the task design highlights the main objectives and keeps 'noise' to the minimum;
   - an explicit strategy is used to stimulate the students' thinking beforehand, so that the practical task is answering a question the student is already thinking about;
   - the task design 'scaffolds' students' efforts to make links between the two domains of knowledge.

5. Practical work of a more open-ended, investigative kind can develop students' tacit knowledge of scientific enquiry. It is, however, hard to argue that this kind of knowledge is needed for 'scientific literacy', though it is clearly of value to students who wish to follow more advanced courses in science. Attempts to include investigative practical work in the mainstream curriculum often result in practice that

is disappointingly different from that intended, especially when students' performance of investigative tasks forms part of the course assessment.

6. Some explicit understanding of the logic of scientific enquiry and of the nature of scientific knowledge is important for scientific literacy. Targeted practical tasks can be very useful for developing such understanding, in particular ideas about data and their interpretation. Again effective tasks have clear and limited objectives, and task designs which focus clearly on this and minimise extraneous 'noise'.

7. For some of the understandings *about* science that we might wish to develop, in particular an understanding of the issues involved in choosing between competing explanations and of the 'closure' of debates, non-practical teaching approaches are also likely to be required.

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Journal of Legal and Political Sociology, 1. Reprinted as â€˜The institutional imperatives of scienceâ€™ in Barnes, B. (ed.) (1972), Sociology of Science (pp. 65-79). Harmondsworth: Penguin Books. 1942. View 4 excerpts. Highly influential. Science for the people. David Layton. 1973. View 3 excerpts. Highly influential. Reasoning from data: How students collect and interpret data in science investigations. Zoe Kanari, Robin Millar. 2004. Conceptual and Epistemic Aspects of Students' Scientific Explanations. William A. Sandoval. 2003. VIEW 1 EXCERPT. Varieties of Labwork: A Way of Profiling Lab Practical work is a prominent and distinctive feature of science education. Many science teachers and others see practical work carried out by the students themselves1 as an essential element of good science teaching. As one teacher put it in an interview study (Donnelly, 1995), â€˜itâ€™s what science is all about really â€¦Â Osborne (1998) argues that practical work â€˜only has a strictly limited role to play in learning science and that much of it is of little educational valueâ€™ (p. 156). Hodson (1991) claims that: â€˜as practised in many countries, it is ill-conceived, confused and unproductiveâ€™ (p. 176). Perhaps a key phrase here is â€˜as practisedâ€™.Â If we are interested in the effectiveness of practical work, we really have to consider specific practical activities that we use, or plan to use. Master of Science in. Educational Leadership. Nazarbayev University Graduate School of Education.Â I confirm that the submission is my original work, and that I have the right to grant the rights contained in this license. I also confirm that my submission does not, to the best of my knowledge, infringe upon anyone's copyright.Â The purpose of this qualitative study was to explore the role of mentoring in teacher professional development in Kazakhstan. Based on empirical evidence and review of relevant literature, this study aimed to identify if or when mentoring plays a significant role in the professional growth of mentors and mentees; if so, how effective this method is and how it influences teacher continuous professional development.