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Teaching and Assessing Practical Skills in Science

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Introduction

**The purpose and contents of the book**

The pressures of time, limited resources and the need to enable students to achieve the best possible results affect most of us as Science teachers. The result can be that we concentrate on the theory contained within the syllabus we use, to the detriment of all but the minimum practical work to get students through that part of the course. However, teaching is about much more than preparing students for examinations. Practical work is essential in enabling students to gain first-hand experience of phenomena. It stimulates curiosity and interest in the subject, helping to develop enquiring minds that want to explore more, offering challenges to existing beliefs.

Where will future scientists come from if we do not inspire our students through experience of practical science – enabling them to see how accepted scientific concepts and bodies of knowledge were discovered, running experiments to produce data to support the theory found in textbooks and giving them the opportunity to develop the skills to carry out original research themselves? Through their own investigative work, they can apply their conceptual understanding in new contexts. Admittedly, some students thrive on theory and we have a challenging job to do in bringing this to life and making it understandable. However, the majority have a range of different preferred learning styles that can only be accessed successfully through hands-on experience – practical work. Nevertheless, it is worth noting that any practical work needs to be thought provoking. Following a list of instructions without understanding the reasons for each stage achieves very little, except to keep students busy. That is not what practical work should be about. Examples are given later in the book of how students can be challenged to think about why they carry out a particular procedure (see, for example, Chapter 6, Table 6.1 – a strategy for building an understanding of how to test a leaf for starch). Other areas of practical work, such as planning, interpreting data, concluding and evaluating, require much
thought: these thought processes will develop in your students as they are exposed to more practicals. The most effective Science teaching operates seamlessly between exploring abstract concepts, illustrative practical tasks, open-ended investigations and teacher-led demonstrations. Any Science lesson should offer constant challenges to get students thinking about all aspects of the topic they are studying.

There are many arguments for and against practical work, considered in Chapter 2. I have written this book to act as a stimulus for you to think carefully about how you approach your teaching, to provide you with ways of generating a real interest in and thirst for Science amongst your students and as a means of sharing experiences so that we all benefit through keeping our teaching fresh. After teaching Science for 23 years, it would be very easy for me to think that I know it all, that my teaching is as good as it is going to get and that work is now plain sailing through to retirement. Well, it isn’t. It never ceases to amaze and delight me that a new student, fresh from university, can start a teaching practice in my department and show me methods of teaching a particular concept in ways I had never thought of. Textbooks appear on the market, dealing with topics that have never been considered in print before. Colleagues teaching a different subject area can come up with suggestions over a cup of tea about how to approach a subject that I find difficult to put across to a class. Teaching Science is never boring. We just need the impetus (and energy!) to keep trying out different ways of teaching. So, whether you have just embarked on a teaching career or have been teaching for several years, this book should provide you with some fresh ideas to make practicals interesting, challenging and exciting for your students. Once you are working towards that goal, everything else is more likely to fall into place amongst your students: high performance in examinations, respect for you as a teacher and a lifelong fascination for the subject.

Sharing is absolutely vital. If you generate a new resource that you find is successful, do not keep it to yourself. Swap ideas, sources and resources with others. Your colleagues are more likely to reciprocate and you should benefit as well. Try to encourage discussions in your own department. Fresh ideas do not necessarily have to come from within your own subject area – as a biologist, I have gained countless ideas from chemists and physicists and have contributed to the development of their practical teaching skills as well. Many practical skills are common to all three areas of Science, so this is hardly surprising.

How often do you get the chance to observe the teaching styles of your colleagues? I firmly believe in an open-door approach to my teaching – anyone is welcome to come into my laboratory, observe me and contribute to my teaching. As a Head of Department, I have roles in
supporting the professional development of colleagues and observing student teachers as they embark on teacher training programmes. This is most definitely a two-way process – I gain as much as I give. Have you considered asking your Head Teacher for some time to allow you to observe other members of staff teaching, including those from other curriculum areas, particularly humanities teaching? The experience is invaluable. Too often we teach in total isolation and, in the process, are starved of fresh ideas, different approaches and strategies.

In this book, I have tried to use real examples of students’ results, graphs, conclusions and evaluations to raise points about aspects of practical work. Because they are genuine, they are rarely perfect. I offer material from the real world, imperfect as it is – I prefer it that way. This is how it is in authentic scientific research. ‘Messy data’ challenges thinking! As these materials stand, they offer numerous points to dwell on, both for you as a teacher and, if you wish to use them as a teaching resource, for your students. Let them study the tables and graphs, pick holes in them and try to suggest improvements. Allow them to try to replicate the experiments, controlling the variables as they see fit to obtain a ‘better’ set of results. They will become more proficient, enthusiastic Science students as a result.

This book is divided into three parts. Chapters 2 and 3 look at the role of practical work in Science, considering its advantages and disadvantages and planning issues, respectively. Chapter 4 outlines the practical skills associated with Science, and Chapters 5 to 11 then look at each of these skills in turn. Finally, Chapter 12 looks at how to assess these skills, including the consideration of which syllabus option to select. There are four appendices. Details of useful sources of information – books, CD-ROMs, professional bodies and websites – can be found in Appendix A. The glossary in Appendix B defines terms that may need clarification, but it does not contain definitions of technical terms in Science. Appendix C provides lists of standard apparatus. Finally, Appendix D contains photocopiable worksheets – these can be enlarged to provide A4 worksheets.

The international education context
During my time (some 13 years now) associated with examining for the International General Certificate of Secondary Education (IGCSE) and in my role as a Principal Examiner, it has been pleasing to see the rise in popularity of Science courses on offer, perhaps partly due to uncluttered syllabuses and the availability of support from professional staff who offer helpful advice. I never cease to be impressed by the number of candidates who use English as a second, or even third, language and yet cope with the rigours of reading and writing extended English. I hope that, through
this book, I have demonstrated that teachers can, even in the most challenging circumstances, use practical work as an invaluable way of engaging students and developing their knowledge and understanding of the subject. It should provide you with the guidance and support to extend your own practical skills, perhaps giving you the confidence to try different or new approaches to your teaching.
2 Practical work in Science

The word ‘Science’ originally meant ‘knowledge’. Even now, it is applied to a wide range of disciplines including political science and the science of philosophy. However, in schools its use tends to be in grouping together three closely linked subjects – Biology, Chemistry and Physics. As teachers, we are well aware that the study of Science involves much more than just the gaining of knowledge (accumulating facts and principles). Any syllabus emphasises the need for students to understand the knowledge they learn, to be able to apply that knowledge to interpret information that is unfamiliar to them, to explain phenomena, patterns and relationships and to solve problems.

Indeed, the body of knowledge that we call Science has been built up over the centuries through observation, investigation and experimentation. As Science teachers, we have a duty to teach students the skills they need to be the scientists of the future. They will, of course, require a sound body of knowledge, but will also need to have the practical skills to extend humankind’s understanding of the world around us, whether it be associated with physical phenomena, materials or living things. For any student, a Science course should be a worthwhile educational experience that is stimulating and challenging, enables the development of new skills and encourages effective communication. All students should learn Science to enable them to make informed decisions as citizens of the twenty-first century. They need to be informed about the controversial issues of Science so they can make balanced judgements about them. For others, learning Science will prepare them for their future role as scientists.

All of the sciences, therefore, have an essentially practical basis. The body of scientific knowledge that students learn in secondary schools has been built up through observation and experiment. It is important that, as well as teaching our students this body of knowledge, we refer to how it has been acquired and the methods by which scientists work. Doing this gives students access to a very large and important area of understanding. Learning through didactic teaching methods may enable a student to
Practical work in Science

draw and label a diagram of the heart, or carry out a calculation using Ohm’s Law, or describe the effect of a rise in temperature on the rate of a chemical reaction. But a good, practical scientific education can achieve much more than this. Young people who have experienced a wide range of practical work will have much more confidence in their ability to tackle new situations, to criticise and evaluate claims made for Science in the media, and – for some – to take their education further.

This chapter highlights the importance to students of carrying out practical work, whilst also recognising the difficulties that some schools face in providing opportunities for undertaking such work.

The importance of practical work in Science teaching

As mentioned above, there are many reasons for including practical work in Science lessons:

- Involvement in practical work helps students to develop the skills of a good scientist – planning investigations and selecting appropriate apparatus, careful observation and measurement, accurate recording and clear display of results, drawing logical conclusions from them and assessing their reliability.
- Carrying out practical work helps students to understand facts and concepts.
- Participation in practical work encourages active learning rather than passive learning, provided the students are required to think about the purpose of the practical activity. It gives students the confidence to think and do for themselves, rather than always relying on the teacher to spoon-feed them with knowledge.
- Practical work can make phenomena more real (see, for example, Figure 2.1).

Figure 2.1: Students investigating the effect of temperature on the rate of enzyme action

6 Practical work in Science
Practical work adds variety and interest to Science lessons. Almost all Science examinations test practical skills in some way. Even if this is done by written assessment – for example Paper 6 in any of the IGCSE Science syllabuses – students will do better in this part of the examination if they have had direct experience of practical work. Practical work helps to develop cross-curricular skills such as communication, literacy, numeracy and ICT. The ability to work as part of a team is often important.

The earlier that practical work can be introduced into a student’s education the better. If you are working in a school that students enter well before their IGCSE years, then it is important to ensure that they do practical work on a regular basis as soon as they start studying Science. By the time they embark on their IGCSE courses, they will be very experienced at doing practicals and will have learned the disciplines required for working in a laboratory.

Difficulties in introducing practical work into Science teaching

Although most Science teachers will agree that their Science lessons should include practical work, in many cases this does not happen. The reasons that teachers give for not doing practical work fall into three main categories:

- lack of facilities;
- time pressure;
- class size.

Lack of facilities

We don’t have good laboratory facilities in my school, there is hardly any equipment and we don’t have a laboratory technician.

A school that attempts to include Science in its curriculum without providing adequate laboratory facilities is not really giving optimum support for its students. These facilities do not need to be sophisticated: the main requirements are a water supply, an electrical supply and some means of heating (Bunsen or spirit burners), plus a safe area where students can work. You will also need a range of containers (preferably but not necessarily glassware) and basic measuring instruments. Obviously, it is desirable to have much more than this, but the lack of sophisticated equipment or facilities is not a reason for avoiding practical work altogether. Schools with very limited resources and facilities need to select carefully practicals that can be carried out with the minimum of
equipment and in ordinary classrooms, or even outside, as fieldwork (see Figure 2.2).

Figure 2.2: Fieldwork is an option when laboratory facilities are limited

Even when a teacher has to rely on demonstrating practicals due to lack of class sets of equipment or poor laboratory facilities, students can be actively involved in the process, changing the learning style from passive to active. Ways of approaching this sort of practical work are considered in Chapter 3.

Appendix C lists appropriate equipment to use in the teaching of IGCSE Biology, Chemistry and Physics. This will be useful for a teacher wishing to extend Science resources or set up a new laboratory. Planning for practical Science in secondary schools, published by Cambridge International Examinations (CIE), contains more detailed information.

Many schools do not have support from laboratory technicians. Once again, although it is obviously very desirable to have such support, it is possible to do a great deal of practical work without it – and very many teachers do. It may be helpful to ask for volunteers amongst your keenest, most reliable students to contribute in a technical role – setting up trays of equipment, washing glassware and so on. If managed well, this can be very prestigious for those students. For a school that gives students badges for key roles (prefect, librarian etc.), a laboratory technician’s badge would be appropriate.
Time pressure

We would never get through the course in time if we did practical work.

If this is a problem for you, then look closely at the time your school allocates for covering the course you are teaching. All of the IGCSE and O Level Science courses, for example, are intended to be taught over two full years, with between 2 $\frac{1}{2}$ and 3 hours a week of contact time. ¹ Each syllabus has been written with the intention that practical work will be an integral part of the course, and the required breadth and depth of treatment of the subject content of the syllabus has been limited accordingly. It can be argued that if practical assessment is worth, for example, 20% of the final mark in an examination (as is the case in IGCSE sciences) then a minimum of 20% of the time should be spent on practical work.

Also, look at the depth to which you cover your subject. Inexperienced teachers often attempt to go into much more detail than is required by the syllabus. This not only takes time, but can also confuse students if difficult concepts are introduced before they are ready to deal with them. Teaching to the level stated in the syllabus and doing plenty of practical work and other activities that develop skills as well as knowledge is the best way of ensuring good examination results.

Class size

I have about 40 students in my classes. We don’t have the space for them all to do practical work, and anyway I would worry about discipline if they were out of their seats and moving around.

There is no doubt that large class sizes make doing practical work very difficult. A sensible maximum is probably about 30, although the size of the room in which they are working will obviously affect this. If you do have very large classes, then consider the possibility of splitting the class for one session a week and using this session for practical work.

Looking Back

- What are the main issues that prevent you from doing practical work or restrict your ability to do so?
- What could you do to overcome these problems?

¹ The IGCSE Coordinated Science course is an exception – this is intended to be covered in double the time that would be appropriate for one single Science course.