Teaching AS Physics Practical Skills
Contents

Introduction 1
  Why should I read this booklet? 1
  How much teaching time should I allocate to practical work? 1
  Can I use the practicals in these booklets in a different order? 1
  What resources will I need? 2
  Is there a limit to the class size? 2
Why should I teach my students practical skills? 3
  Points to consider 3
What are the practical skills required by this course? 5
  Summary of each of the seven skills 5
  A sequence for introducing the skills 7
Ways of doing practical work 9
Keeping records 12
How is a practical activity organised? 13
Teaching AS skills 15
  Teaching students to set up and manipulate apparatus 15
  Teaching students to make measurements and observations 15
  Teaching students to record and present observations and data 17
  Teaching students to analyse data and draw conclusions 19
  Teaching students to evaluate procedures 21
Designing a practical course for the AS year 23
  Planning the course 23
  Planning lessons and teaching the course 24
  Planning for a circus 25
Appendix 1: Possible AS practical activities 26
Appendix 2: Examples of AS practicals 37
  Terminal Velocity 38
  Acceleration down a Slope 42
  Triangle of Forces Board 47
  Finding the Mass of a Metre Rule using the Principle of Moments 51
  Finding the Densities of Different Materials 55
  Elasticity and Springs 60
  Finding the Young Modulus of a Wire 65
  Measuring the Resistivity of a Wire 70
  Potential Divider 74
  Measuring g using a Pendulum 78
Appendix 3: Useful resources 82
Introduction

You may have been teaching AS and A level physics for many years or perhaps you are new to the game. Whatever the case may be, you will be keen to ensure that you prepare your students as effectively as possible for their examinations. The use of a well-structured scheme of practical work will certainly help in this ambition. However it can do so much more. Science students who are thoroughly trained and experienced in practical skills will have a ‘feel’ for the subject and a confidence in their own abilities that is far greater than that of students with a purely theoretical background. It is true that there are branches of physics that might be described as purely theoretical but they are in the minority. Essentially, physics is an experimental subject and we owe it to our students to ensure that those who pursue science further have the necessary basic practical skills to take forward into their future careers. Furthermore, the basic skills of planning, analysis and evaluation will be of great value to those who pursue non-science careers.

Why should I read this booklet?

You may be wondering why you should need a booklet like this. If your practical skills are of a high order and you feel confident teaching these skills to others, you probably don’t need it (although you might find some of the exercises described in the appendices useful). However, if you are like the majority of us, a little help and support is likely to be appreciated. This booklet aims to provide at least some of this support.

The booklet is designed for the teacher, not for the student. Its objective is to provide a framework within which teachers can develop their confidence in teaching practical skills. Experience suggests that as this confidence grows, the time that teachers are prepared to spend on teaching practical skills also grows.

How much teaching time should I allocate to practical work?

The syllabus stipulates that at least 20% of teaching time should be allocated to practical work. This is in addition to any time the teacher chooses to use for practical demonstrations to illustrate the theory syllabus.

This emphasis on practical work is not misplaced. If the specific practical papers (papers 3 and 5) are considered in isolation, they represent 23% of the examination. However, practical work is not merely a necessary preparation for the practical papers. Questions in the theory papers may also assume an understanding of experimental data or practical techniques. The theory papers also give a considerable weighting to the skills of handling, applying and evaluating information, and one of the ways in which students acquire these skills is through their course of practical work.

In planning a curriculum, teachers should therefore expect to build in time for developing practical skills. If, for example, the total teaching time allowed for Physics is 5 hours per week over 35 weeks, then a minimum of 1 hour per week for practical work should be built into the plan. In this way, over the year a minimum of 35 hours for practical work is made available. Bearing in mind the weighting given to assessment objectives that relate to information handling and problem solving, 35 hours of practical work should be regarded as an absolute minimum.

Can I use the practicals in these booklets in a different order?

It is assumed in these booklets that for A level candidates, the AS work will be taught in the first year of the course, with the A2 work being covered in the second year. If the linear A Level assessment route is used, care should be taken with regard to the order in which practical exercises are used, as the skills practiced in these booklets are hierarchical in nature, i.e. the basic skills established in the AS booklet are extended and developed in the
A2 booklet. Thus, students will need to have practiced basic skills using AS exercises before using these skills to tackle more demanding A2 exercises.

The exercises in these booklets are given in syllabus order. A teacher may well decide to use a different teaching sequence, but the point made above regarding AS and A2 exercises still applies.

**What resources will I need?**

For a practical course in A-level physics to be successful, it is not necessary to provide sophisticated equipment. Some of the more advanced practicals in these booklets may require less easily obtainable equipment, but the vast majority can be performed using the basic equipment and materials in the laboratory.

A list of basic resources regularly required for assessment may be found in the syllabus. A more detailed list of apparatus suitable for teaching purposes may be found in the CIE booklet ‘Planning For Practical Science in Secondary Schools’.

**Is there a limit to the class size?**

There is a limit to the class size that is manageable in a laboratory situation, particularly when students may be moving about. The actual size may be determined by the size of the room, but as a general guide, 15 - 20 students is the maximum that one teacher can reasonably manage, both for safety reasons and so that adequate support can be given to each student. Larger numbers would require input from another person with appropriate qualifications, or alternatively would require the class to be divided into two groups for practical lessons.
Why should I teach my students practical skills?

Although this section is likely to be read once only, it is arguably the most important, for, if it convinces some readers that practical work is an essential part of physics and underpins the whole teaching programme, one of the aims of publishing this booklet will have been achieved.

Points to consider

- It’s fun! The majority of students thoroughly enjoy practical work. The passion that many scientists have for their subject grew out of their experiences in practical classes. Students who enjoy what they are doing are likely to carry this enthusiasm with them and so be better motivated in all parts of the course.

- Learning is enhanced by participation as students tend to remember activities they have performed more easily, thus benefitting their long-term understanding of the subject. Students who simply memorise and recall facts find it difficult to apply their knowledge to an unfamiliar context. Experiencing and using practical skills helps develop the ability to use information in a variety of ways, thus enabling students to apply their knowledge and understanding more readily.

- The integration of practical work into the teaching programme quite simply brings the theory to life. Teachers often hear comments from students such as “I’m glad we did that practical because I can see what the book means now.” and “It’s much better doing it than talking about it.”

- Physics, in common with other sciences, is by its very nature a practical subject – both historically and in the modern world. The majority of students who enter careers in science need to employ at least basic practical skills at some time in their career.

- A practical course plays a part in developing many cross-curricular skills including literacy, numeracy, ICT and communication skills. It develops the ability to work both in groups and independently with confidence. It enhances critical thinking skills and it requires students to make judgements and decisions based on evidence, some of which may well be incomplete or flawed. It helps to make students more self-reliant and less dependent on information provided by the teacher.

- The skills developed are of continued use in a changing scientific world. While technological advances have changed the nature of many practical procedures, the investigative nature of practical science is unchanged. The processes of observation, hypothesis formation, testing, analysis of results and drawing conclusions will always be the processes of investigative science. The ability to keep an open mind in the interpretation of data and develop an appreciation of scientific integrity is of great value both in science and non-science careers.

- Practical work is not always easy and persistence is required for skills and confidence to grow. Students often relish this challenge and develop a certain pride in a job well done.

- The more experience students have of a variety of practical skills, the better equipped they will be to perform well in the practical exams, both in terms of skills and confidence. Some teachers have argued that the skills required for paper 3 can be developed simply by practising past papers. However, experience suggests that this approach does not usually produce good results, and that confidence in practical work will be greatly enhanced by a broader range of practical experience. Similarly for paper 5, it has been suggested that planning, analysis and evaluation could be taught theoretically. However, without hands-on experience of manipulating their own data, putting their plans into action and evaluating their own procedures and results, students will find this section difficult and will be at a distinct disadvantage in the examination. Those students
who achieve the highest grades do so because they can draw on personal experience, and so are able to picture themselves performing the procedure they are describing, or recall analysing their own results from a similar experiment. Students with a bank of practical experience are much more likely to perform well than those with limited practical skills.
What are the practical skills required by this course?

The syllabus specifies the practical skills to be assessed by providing generic mark schemes for the practical papers. These mark schemes divide practical skills into four broad areas.

- Manipulation, measurement and observation AS
- Presentation of data and observations AS
- Analysis, conclusions and evaluation AS and A2
- Planning A2

For teaching purposes, it is helpful to subdivide the first and third of these broad areas into slightly narrower ones. Students will also find it helpful to think about the sequence in which practical skills are used in a typical scientific investigation.

This course addresses practical skills under seven headings that contribute to the overall understanding of scientific methodology. In a scientific investigation these would be applied in the following sequence.

1 Planning the experiment
2 Setting up and manipulating apparatus
3 Making measurements and observations
4 Recording and presenting observations and data
5 Analysing data and drawing conclusions
6 Evaluating procedures
7 Evaluating conclusions

It is easy to see how these seven skills are related to the four areas in the syllabus.

The emphasis of the AS part of the course is on skills 2, 3, 4, 5 and 6. In other words, students have to master the basic skills of manipulating apparatus, making measurements, displaying their data in tables and on graphs, and drawing conclusions. They also have to learn to critically evaluate the experimental procedures by identifying limitations and sources of error and by suggesting improvements.

The A2 syllabus concentrates on skills 1, 5 and 7 – the higher-level skills of planning, data analysis and evaluation. All of the skills developed in the AS part of the course are assumed to have been mastered and skill 5 is extended and deepened. The A2 skills can only be developed by allowing students to take a greater degree of control over the procedures they use in practical classes.

Summary of each of the seven skills

Full details of the requirements for each of these skills may be found in the syllabus. What follows below is a brief summary of the skills involved.

1 Planning

- Defining the problem
  Students should be able to use information provided about the aims of the investigation, or experiment, to identify the key variables.

- Methods of data collection
  The proposed experimental procedure should be workable. It should, if the apparatus were to be assembled appropriately, allow data to be collected without undue difficulty. There should be a description, including clear labelled diagrams, of
how the experiment should be performed and how the key variables are to be controlled. Equipment, of a level of precision appropriate for the measurements to be made, should be specified.

- **Method of analysis**
  Students should be able to describe the main steps by which their results would be analysed in order to draw valid conclusions. This may well include the proposal of graphical methods to analyse data.

- **Safety considerations**
  Students should be able to carry out a simple risk assessment of their plan, identifying areas of risk and suggesting suitable safety precautions to be taken.

2 **Setting up and manipulating apparatus**

Students must be able to follow instructions, whether given verbally, in writing or diagrammatically, and so be able to set up and use the apparatus for experiments correctly. They will need to be able to work with a variety of different pieces of apparatus and to work from circuit diagrams.

3 **Making measurements and observations**

Whilst successfully manipulating the experimental apparatus, students need to be able to make measurements with accuracy and/or to make observations with clarity and discrimination. They may need to be able to use specific measuring instruments and techniques, such as Vernier scales, cathode-ray oscilloscopes, or Hall probes. They need to be able to manage their time while they make measurements, and to be able to make decisions about when it is appropriate to repeat measurements. They need to organise their work so that they have the largest possible range of readings and so that the readings are appropriately distributed within that range. They should be able to identify and deal with results which appear anomalous.

4 **Recording and presenting observations and data**

Observations, data and reasoning need to be presented in ways that are easy to follow and that accord with conventional good practice.

- **Tables of results**
  The layout and contents of a results table, whether it is for recording numerical data or observations, should be decided before the experiment is performed. ‘Making it up as you go along’ often results in tables that are difficult to follow and don’t make the best use of space. Space should be allocated within the table for any manipulation of the data that will be required. The heading of each column must include both the quantity being measured and the units in which the measurement is made. Readings made directly from measuring instruments should be given to the number of decimal places that is appropriate for the measuring instrument used (for example, readings from a metre rule should be given to the nearest mm). Quantities calculated from raw data should be shown to the correct number of significant figures.

- **Graphs**
  Students should label the axes of their graphs clearly with the quantity, unit and scale all clearly shown in accordance with conventional good practice. Scales should be chosen so that the graph grid is easy to use and so that the plotted points occupy the majority of the space available. All of the points in the table of results should be plotted accurately. Students should be able to draw curves, tangents to curves or lines of best fit.
• **Display of calculations and reasoning**

Where calculations are done as part of the analysis, all steps of the calculations must be displayed so that thought processes involved in reaching the conclusion are clear to a reader. Similarly, where conclusions are drawn from observational data, the key steps in reaching the conclusions should be reported and should be clear, sequential and easy to follow.

5 **Analysing data and drawing conclusions**

Students should be able to calculate the gradient and intercepts of a line, including finding the intercepts when a false origin has been used on the graph. They should be able to use these to find the equation of the line of best fit through their points. They should be able to relate an equation predicted by theory to the equation of their line of best fit or to their data, and hence to find the values of constants or to draw conclusions about the veracity of the theoretical prediction. They should be able to use the idea of proportionality in their reasoning. They should be able to make predictions or hypotheses based on their data.

In the AS part of the course, students would normally be told what quantities to calculate, what graph to plot and would be led through the analysis. In the A2 part of the course, students would normally be expected to be able to plan the analysis for themselves. This would normally include deciding what quantities to plot in order to obtain a straight-line graph, deciding how to calculate these quantities from their raw data, and deciding how to reach a conclusion from their graph.

6 **Evaluating procedures**

Students should be able to identify the limitations and weaknesses of experimental procedures. To be able to do this effectively, they must have a clear idea of the purpose of the experiment, and they must have carried out the procedure for themselves. They should be able to make reasonable estimates of the uncertainties in the quantities they have measured directly, and to compare these so that they can identify the largest sources of error. They should be able to suggest improvements to the experimental procedure which would improve the accuracy or reliability of the experiment.

7 **Evaluating conclusions**

This skill is primarily concerned with the treatment of errors. Where the outcome of an experiment is the value of a constant, the treatment of errors should lead to an estimate of the uncertainty in the student’s value. Where the experiment is a test of a hypothesis, the treatment of errors should allow the student to discuss the validity of their conclusion in terms of the precision of the experimental procedures.

As part of the treatment of errors, students should be able to make estimates of the uncertainties in their measurements, calculate the uncertainties in derived quantities, display error estimates in tables of results, plot error bars on their graphs, and estimate the uncertainties in their calculations of gradients and intercepts.

**A sequence for introducing the skills**

The above list shows the seven skills in the order in which they would be used in an extended investigation. It is not suggested that these skills should be taught in this order (although students will find it helpful to understand how the skills fit together in an investigation).

Students who are new to practical work will initially lack the basic manipulative skills, and the confidence to use them. It would seem sensible, therefore, to start practical training with skills 2 and 3, initially with very simple tasks and paying attention to the establishment of safe working practices. These short initial exercises should focus on training students in the setting up of common items of apparatus (such as power supplies and stands, bosses and
clamps) and in the use of simple measurement techniques (such as the use of rules, stopwatchs and electrical meters).

Once a measure of confidence in their manual dexterity has been established, AS students can move on to exercises that require skills 4 and 5 to be included. The exercises should be simple at first and grow in complexity. Extensive experience in carrying out practical procedures allows students to gain awareness of appropriate quantities and to become more organised in the management of time and the recording of data as it is collected.

It is likely that skill 6, Evaluating Procedures, will be the most difficult to learn at AS level. Critical self-analysis does not come easily to many people. ‘My experiment worked well’ is a common – and inadequate – student evaluation of an experiment. If students are to master this skill, they need to begin by developing an appreciation of the reliability and accuracy inherent in the equipment and procedures they are using. Exercises with less reliable outcomes can be used to provide more scope for the evaluation of procedural, technical or apparatus weaknesses.

In the AS year, most practical tasks will include instructions on what apparatus to use, how to set it up, what data to collect, and what graphs to plot. The skills under development in the AS year are concerned with being able to carry out these tasks effectively, and to evaluate what they have been asked to do. In the A2 year, students should begin to take more control over decision-making. This will include some exercises to develop skill 5: such exercises might provide instructions on what apparatus to use and what data to collect, but leave students to decide on how to conduct the analysis of their data, including decisions about what graph to plot. Practical work at this stage will also include some exercises to develop some aspects of skill 1, for example by telling students what data they need to collect but requiring them to decide how to collect it with the apparatus provided.

The evaluation of conclusions, skill 7, is essentially about the propagation of errors. This requires a high degree of familiarity not only with the basic ideas of uncertainty in measurements but also with the analysis of experimental data, and so is an A2 skill. This skill should be introduced early in the A2 year and students should then regularly be required to practice their skill with the treatment of errors.

Planning is arguably the most demanding of the seven skills. For it to be effective, students need to be very well grounded in skills 2-6, so that they can anticipate the different stages involved in the task, and can provide the level of detail required. It is for this reason that planning skills are not assessed at AS level but form part of the A2 assessment. Candidates cannot be taught to plan experiments effectively unless, on a number of occasions, they are required:

- to plan an experiment;
- to perform the experiment according to their plan;
- to evaluate what they have done.
Ways of doing practical work

Physics teachers should expect to use practical experiences as a way to enhancing learning. Practical activities should form the basis on which to build knowledge and understanding. They should be integrated with the related theory, offering opportunities for concrete, hands-on, learning rather than as stand-alone experiences. In planning a scheme of work it is important to consider a mosaic of approaches that include those that allow students to participate in their own learning.

- Some practical activities should follow the well established structure that includes a detailed protocol to follow. Such well-structured learning opportunities have a vital role to play in introducing new techniques.

- Other practical activities should offer the students the opportunity to devise their own plan and to apply their plan to solving a problem. The excitement generated by such autonomy provides a stimulus to engage a student's interest and challenge their thinking.

Practical activities may be used as a tool to introduce new concepts – for example by investigating the properties of new circuit components or of pieces of polaroid, followed up by theoretical consideration of the reasons for the results obtained. On other occasions, practical work can be used to support and enhance the required knowledge and understanding – for example in building upon a theoretical consideration of diffraction with a series of practicals involving light, water waves and microwaves. In all cases, learning will be enhanced most effectively by practical work that encourages students to be involved, to think, and to apply and use their knowledge, understanding and skills.

There are many strategies by which practical work can be integrated into a scheme of work. Teachers should use a variety of methods. Some of the ways of delivering practical work enable the teacher to interact on a one-to-one basis with individual students, which allows a teacher to offer support at a more personal level and develop a greater awareness of an individual student’s needs.

The choice of the specific strategy to use will depend on such issues as class size, laboratory availability, the availability of apparatus, the level of competence of the students, availability and expertise of technical support, the time available, the intended learning outcomes for the activity, and safety considerations. The following are some possible strategies for delivery of practical work.

- **Teacher demonstrations**
  
  Teacher demonstrations require less time than full class practicals, but give little opportunity for students to develop manipulative skills or gain familiarity with equipment. Careful planning can give opportunity for limited student participation. Teacher demonstrations are a valuable way of showing an unfamiliar procedure at the start of a practical session, during which students go on to use the method themselves.

  Considerations when deciding whether to do a teacher demonstration might include:
  
  i  **Safety** – some exercises carry too high a risk factor to be performed in groups.
  
  ii  **Apparatus** – complicated procedures or those using limited resources
  
  iii  **Time** – demonstrations usually take less time
  
  iv  **Outcome** – some results are difficult to achieve and may be beyond the skill level of most of the students. A failed experiment may be seen as a waste of time, although it may allow students to learn from their mistakes.
  
  v  **Students’ attention** – a danger is that the attention of some students will drift.
  
  vi  **Manipulative experience** – the teacher gets experience, the students’ don’t.
There are many good reasons for the teacher performing a demonstration but do be aware that most students have a strong preference for hands-on experimentation. So, where possible, do let them do it!

- **Group work**

  **Whole class practical sessions.** These have an advantage in terms of management as all the students are doing the same thing. Students may be working individually, in pairs or in small groups. Integrating this type of practical is straightforward as lessons beforehand can be used to introduce the context and following lessons can be used to draw any conclusions and to develop evaluation. Where specialised equipment or expensive materials are in short supply this approach may not be feasible.

  **Small group work.** This can provide a means of managing investigations that test a range of variables and collect a lot of measurements. Although the same procedure may be performed, each small group of students collects only one or a few sets of data which are then pooled. The individual student has the opportunity to develop their subject specific skills. Part of the role of the teacher is to monitor and maintain safety and also to enable and persuade reluctant learners to take part. Group work aids personal development as students must interact and work co-operatively.

  Considerations when deciding whether to do group work might include:

  i  **Learning** – successful hands-on work will reinforce understanding; also, students will learn from each other.

  ii  **Confidence** – this will grow with experience

  iii  **Awareness/insight** – should grow with experience

  iv  **Team building** – a most desirable outcome.

  v  **Setting out** – all students doing the same thing is easier for the technicians

  vi  **Confusion** – incomplete, ambiguous or confusing instruction by the teacher will waste time while the instructions are clarified but may also compromise safety and restrict learning.

  vii  **Opting out** – some students will leave it for others to do and so learn very little.

  viii  **Safety** – constant vigilance is essential.

  ix  **DIY** – the urge to adapt their experiments, to ‘see what would happen if’, must be strictly dealt with.

  x  **Discipline** – practical time must not be allowed to become ‘play time’.

  Working in groups, whether as part of a whole-class situation or where groups are working as parts of a whole, is probably the preferred option for many students. At A level, it is highly desirable to include opportunities for students to work on their own, developing their own skills and independence. In Papers 31 and 32, a student’s practical skills will be assessed on an individual basis, so an individual’s experience, competence and confidence are of considerable importance.

- **Circus of experiments**

  A circus comprises of a number of different exercises that run alongside each other. Individual or groups of students work on the different exercises and, as each exercise is completed, move on to the next one. These are a means by which limited resources can be used effectively.

  There are two basic approaches. Firstly, during a lesson a number of short activities may be targeted at a specific skill. Alternatively, over a series of lessons, a number of longer practical activities are used, addressing a variety of skills. The circus arrangement may be
more difficult to manage as the students are not all doing the same activity. This puts more pressure on the teacher as they have to cope with advising and answering questions from a variety of investigations. With circuses spread over a number of sessions, careful planning is needed to enable the teacher to engage each group of students and to maintain a safe environment. In these situations it is useful to have a few of the circus activities that involve no hands-on practical work, using data response based simulations or other activities. In this way the teacher can interact with groups that need a verbal introduction or short demonstration and can monitor their activities more effectively.

Considerations when deciding whether to do a circus of experiments might include:

i  **Apparatus** – if the amount of apparatus used in an exercise is limited, students are able to use it in rota.

ii  **Awareness** – students by observing their peers will become more aware of the pitfalls of the exercise and so will learn from the experience of others.

iii  **Safety** – different exercises may well carry different safety risks, all of which would need to be covered.

iv  **Setting out** – students doing different exercises will make it more difficult for the technicians.

v  **Opting out** – some students may be tempted to ‘borrow’ the results of earlier groups.

- **Within theory lessons**
  This option should be considered whenever it is viable. It is likely that the practical work would be by demonstration, as this would take less time. Given the power of visual images, the inclusion of a short practical to illustrate a theoretical point will reinforce that point and so aid the learning process. It is critical, however, that the practical works correctly, otherwise the flow of the lesson is disrupted and confidence in the theory may be undermined. The exercise should therefore be practiced beforehand.

- **Project work**
  Projects are a means by which a student’s interest in a particular topic, which is not always directly on the syllabus, can be used to develop investigative skills. This sort of investigative work can be individual, or a group activity. Once the project is underway, much of the work can be student-based, although if it is practical it needs to be undertaken under the supervision of the teacher for safety reasons. Care is needed in selecting the topics and setting a time scale, so that the relevance is maintained to the syllabus context.

- **Extra-curricular clubs**
  The role that these can play is in stimulating scientific enquiry methods. There are a number of ways of using clubs. One way is to hold the club session during the teaching day so that all students can attend. In effect this becomes additional lesson time in which students can practice investigative skills, including laboratory work. Such laboratory work involves materials that have a cost, which must be planned for beforehand. If however the club is held outside the teaching day it may be voluntary. Syllabus-specific activities should be limited and the most made of the opportunities for exciting work unrelated to syllabuses. Students who do attend the club could be used as a teacher resource by bringing back their findings to a classroom session.
Keeping records

Students often find it a problem to integrate the practical work and the theory. This is particularly true when a circus of experiments or a long-term investigation or project is undertaken. Some potential issues include:

- Some students use odd scraps of paper in the laboratory, which are lost or become illegible as water is spilled on them. One important criterion is that students are trained to immediately and accurately record results.

- Practical procedures may be provided on loose sheets of paper which are subsequently lost, or students write down the results from a teacher demonstration. In either situation, students end up with results but no procedure or context.

- When results take a period of time to collect, analysis becomes isolated from the context of the investigation and may not be completed.

The key to minimising these issues is to train students into good working practices. This is particularly important in colleges where students join at the start of their A levels from a variety of feeder schools. It is also vital for students with specific learning difficulties that affect their ability to organise their work such as dyslexia and Asperger’s syndrome.

Students may be encouraged to integrate the practical in the same file as the theory. Alternatively, students may be encouraged to keep an entirely separate practical book or file. Loose leaf files make it easy to add to the file, but may make it easier to mix up or lose items. Exercise books can be used but students should be encouraged to glue worksheets and their laboratory records into the book so that they are not lost. Depending on how they learn, individuals may vary in their preferred method. Whichever option is chosen, students need to be encouraged to relate their investigations to the appropriate theory and to regard it as something that needs to be thoroughly assimilated.

- Integrating the materials generated by practical work with the notes and other items from the learning of theory can be achieved by interspersing the records of investigations with the relevant section of theory. This may still require cross-referencing where several learning outcomes and assessment objectives are targeted by work.

- Keeping a separate practical book enables records of all the practical investigations to be kept in one place. Students need training to manage practical files effectively, particularly in keeping the contexts and cross referencing to the theory. If care is not taken to develop and keep up these skills, students may perceive practical work as something entirely different from theory.

- An intermediate between these two extremes is having a separate section for practical investigations in each student’s file with each syllabus section and cross referenced to the relevant theory.
How is a practical activity organised?

Preparing for practical work needs thought and organisation. The practical work may be an activity that forms part of a lesson, it may comprise an entire lesson, or it may be an investigation designed to last for several lessons. In every case, thorough preparation is a key prerequisite to success.

Practical and investigative work should be integrated into the programme of study. The scheme of work should identify appropriate practical investigative experiences for use at the most suitable time. In designing the scheme of work,

- the resource implications should be considered in terms of equipment and materials in stock,
- the time taken from order to delivery and the cost of materials to be obtained from suppliers should be considered
- careful scheduling may be needed in Centres with a large number of students. It may be possible to permit several groups to do the work simultaneously or in quick succession, or it may be essential to re-order the scheme of work for different groups so that scarce resources can be used effectively.
- note must be taken of national or local health and safety regulations relating to laser light, high voltages, chemicals etc. There may also be regulations controlling the use of radioactive sources.

Once the scheme of work has been established, the next stage is to consider each practical activity or investigation. In an ideal course, each of the following stages would be gone through in developing each practical exercise in a course. This is not always realistically possible the first time through a course, and in such circumstances it is better to get some practical work done with students than to hold out for perfection before attempting anything. Obviously, all practical work should be subject to careful and rigorous risk assessment, no matter how provisional the rest of the supporting thinking and documentation may be.

- Decide on the aims of the work – the broad educational goals, in terms of the practical skills involved (e.g. evaluating procedures) and the key topic areas (e.g. deformation of solids)
- Consider the practical skills being developed. Reference should be made to the syllabus, which in the Practical Assessment section includes learning outcomes relating to practical skills. For instance, if the practical work intended is to be a planning exercise, which of the specific skills identified in the learning outcomes will be developed?
- With reference to the topics included, decide on the intended learning outcomes of the practical activity or investigation, again referring to the syllabus. For instance, which of the “waves” learning outcomes will be achieved? In some cases during the course, the material on which the practical is to be based may be unfamiliar, in which case there may be no topic-related intended learning outcomes. Thus, A2 contexts may be used for AS practicals, and topic areas not on the syllabus at all may be used for AS or A2 practicals.
- In addition, it is useful to assess any other context of the practical work investigation. For instance, is it intended as part of the introduction of a concept, or to support a theory, or to demonstrate a process?
- Produce a provisional lesson plan, allocating approximate times to introduction, student activities and summarising.
• Produce and trial a student worksheet. Published procedures or those produced by other teachers can be used. Alternatively produce your own. As a rule schedules produced by others need modifying to suit individual groups of students or the equipment available. It is helpful to ask students or another teacher to read work sheets before they are finalised as they can identify instructions that are ambiguous or that use inaccessible terminology.

• Refine the lesson plan in relation to the number of students for which the investigation is intended (whole class or a small group), the available equipment (does some have to be shared?) and materials. There are examples of lesson plans and student work sheets in Appendix 2.

• Carry out a detailed and careful risk assessment before any preparatory practical work is done, and certainly well before students do any of the practical work. You should consider
  o the likelihood that any foreseeable accident might occur.
  o the potential severity of the consequences of any such accident.
  o the means that can be taken to reduce the severity of the effect of any accident.

• Make an equipment and materials list. This should include
  o apparatus and materials (including quantities) per student or per group.
  o shared equipment per laboratory (e.g. sinks, top-pan balances).
  o the location of storage areas for equipment and materials.

• Set up and maintain a filing system where master copies of the work sheets, lesson plans and equipment lists can be stored. It is helpful to have these organised, or at least indexed, in both their syllabus context and skills developed.

• Once an investigation has been used by a group of students it should be evaluated in relation to intended outcomes and the lesson plan. It is important to obtain feedback from the students about their perception of the work. For example,
  o was the time allocation appropriate?
  o were the outcomes as expected?
  o did the students enjoy the work?
  o did the students understand the instructions?
  o was the point of the work clear to the students?

If necessary the work sheet and lesson plan should be revised.
Teaching AS skills

Teaching students to set up and manipulate apparatus

Some students will begin their AS course with very little experience of hands-on practical work, and consequently with limited knowledge of apparatus and limited skill in manipulating it. In this situation it is often sensible to begin a practical course with a circus of very short exercises designed solely to enable students to gain familiarity with common pieces of apparatus.

As an example, such a circus of short exercises might include practice in the use of retort stands, bosses and clamps. Clamping a half-metre rule so that it is exactly horizontal and a specified height above the bench is quite fiddly for inexperienced students and will teach them familiarity not only with the use of a stand, boss and clamp but also with the use of a set square and 30 cm rule to check that the rule is exactly horizontal. Setting up a simple pendulum of a specified length with the string clamped between two blocks of wood is similarly quite difficult and allows students an opportunity to think about why pendulums are set up in this way rather than, for example, by tying the string to the clamp.

Many students will need to be taught how to relate a circuit diagram, conventionally printed with straight lines and right angles, to the rather less tidy appearance of a real circuit. This can begin to be taught by asking students to draw a circuit diagram of a given series circuit, by tracing the wires from the positive to the negative terminal of the power supply. Students can then move on to more complex circuits with parallel branches. After this, students can be asked to use the same approach (of tracing the wires from the positive to the negative terminal of the power supply) to set up real circuits from circuit diagrams. In the initial stages it may be helpful to label circuit components and to provide a key to circuit symbols: students will learn to recognise both the components and the symbols as the course progresses, and after a while the labels can be dispensed with. The ability to connect circuits correctly from circuit diagrams will be needed (and hence reinforced) regularly during the course, particularly during the teaching of the whole of Section V of the syllabus, and the more often it is practised the better.

It is important that the students become confident with all the common apparatus that they may come across. During the course of the year they should all have experience of using as much of the common apparatus as listed in the syllabus and the CIE booklet ‘Planning For Practical Science in Secondary Schools’ (June 2002). They need to be able to recognise different items of apparatus as well as learning to use them. In some cases it may be worth the students being encouraged to keep a skills and equipment log where they could record the apparatus and techniques that they have gained over the year.

Students’ manipulative skills will develop over the course of the year. Some of this learning will take place in short exercises designed to introduce students to particular pieces of apparatus. Some of it (and much of the reinforcement) will take place while students are performing more involved experiments. The course should be designed to include some experiments which require some delicate manipulation and which may take some time to get to work successfully, such as the experiment to find the mass of a metre rule.

During the early part of the course some students will lack confidence and will need to be encouraged and supported. As the course continues and their experience grows, these students will become more confident and self reliant in practical situations.

Teaching students to make measurements and observations

Measurements are an integral part of Physics practical work. All of the practicals that are covered in the appendices to this booklet, and the questions in practical examination papers, will require multiple measurements to be made. In most situations, the measurements have to be made successfully before the student can move on to the next stage of the experiment.
At the beginning of the course, some students may have had little previous exposure to practical work and may lack confidence in making measurements and observations. Such students may be helped by a series of very short exercises designed simply to provide familiarity with the most common measuring devices. These exercises could form part of the same circus used to introduce them to other items of apparatus or to manipulative skills.

Familiarity with the use of measuring instruments can be gained both by short, highly-focused exercises and by practice during longer, full-lesson practicals. Both approaches should be used. Every opportunity should be taken to give students practice in making measurements, even if this is part of a demonstration.

Students should be taught to look for situations in which the precision of measurements can be improved by measuring a multiple of the quantity. For example, the period of an oscillation can be more accurately measured by timing ten or twenty periods and then dividing by the number of periods. A similar principle can be applied to a wide variety of other measurements, for example measuring the thickness of twenty sheets of paper instead of just one, or the mass of fifty coins instead of just one. Students need to be encouraged to think about why this reduces the uncertainty in the measurement. They need to be given exercises in recognising such situations as well as being given practical work that requires them to use the technique.

The use of Vernier scales and micrometer screw gauges is something that particularly benefits from a dedicated activity to familiarise the students using them for the first time. As they will be used many times during subsequent practical sessions, this is time very well spent. There are also a number of internet-based activities that can be used to familiarise students with reading these scales.

The most common measuring instruments used in the AS level course will include millimetre scales on rules of various lengths, micrometer screw gauges, Vernier callipers, measuring cylinders, protractors, stopwatches, top-pan balances, newton-meters, thermometers, ammeters, voltmeters and cathode-ray oscilloscopes. Some students will also have access to light gates and electronic timing equipment.

It may be that the electrical meters generally used are all either digital or analogue, but students need to have some experience of reading from both types of scale. Some analogue meters have more than one scale printed on their faces, and students should be taught to recognise which scale to use.

Digital multimeters are both more versatile and considerably cheaper than the single-range meters available from specialised school laboratory equipment suppliers. Consequently many schools now only use digital multimeters. Students need to be taught how to select the appropriate range and the appropriate sockets on a digital multimeter, and to be given regular practice in their use.

Students are expected to be familiar with the precision of the measuring instrument used. This will need to be taught directly when each new measuring instrument is used for the first time. Each time the measuring instrument is used again, students should be encouraged to remember or identify the level of precision of the instrument. They should eventually know the levels of precision for most of the common measuring instruments and have the skills to be able to make a reasonable judgement when they forget or when they encounter a less familiar measuring instrument.

When considering the precision of a measuring instrument, students need to know when to interpolate between scale marks and when this is not appropriate. There are differing schools of thought on this question. At A/AS level, students are not expected to interpolate except when the smallest scale divisions are further apart than about 1 mm (which is not very common).
Students are expected to record their measurements to a degree of precision that is appropriate for the experiment. Sometimes this will be the same as the precision of the measuring instrument, and sometimes there will be reasons why the data is less precise than the measuring instrument used. (Examples include accurate stopwatches, where the reaction time of the operator is significant; or measurements of the amplitude of an oscillation, where the movement may be too rapid to be measured to the nearest millimetre). Students need to be trained to think about the appropriate degree of precision for their measurements, and this will not always be obvious to them. It will help them to learn if they are required to record their thought processes: if this is a consistent requirement it will eventually become second nature.

Where readings are repeated, the range of values obtained provides useful information about the uncertainty in the measurement. The average of the repeated readings should be calculated and used as the value of the measurement in subsequent stages of the experiment. The range in the value of the readings should be treated as twice the error in the measurement.

Students are also expected to know when to repeat readings and when not to. As with many other practical skills, this can be discussed initially and then reinforced by constant practice. It is not normally necessary to repeat all measurements, but it is usually good practice to repeat those that appear to be the largest sources of percentage error, or those where repeat readings can provide information about the uncertainty.

The terms precision, accuracy, error and uncertainty can cause much confusion in students' minds, and their meanings should be addressed directly early on in the course. Error and uncertainty are interchangeable terms in A/AS level, but the distinction between precision and accuracy is one that students are expected to understand.

**Teaching students to record and present observations and data**

Most of the observations and measurements that students make will be presented in tables of results and graphs. There are conventions for both tables and graphs that students have to learn and follow. They will find it easier to learn if the reasons behind the conventions are explained. Once it has been explained, constant reinforcement will make the conventions second nature.

When plotting tables of results, students need to:

- think ahead so that they have space for all the columns;
- show the quantity and unit in the column headings;
- be consistent in the degree of precision for each column of raw data;
- use the correct number of significant figures in calculated quantities.

Thinking ahead is not something that all students do naturally. To help them, they should be encouraged to draw out the framework of the table of results, with all the column headings in place, before they start to make the measurements and insert in the values.

For most experiments, two quantities are measured directly, and these will require a column each. Often there will be a need to repeat readings for one of these quantities: this will add to the number of columns. In addition, calculated quantities will often be needed for plotting on the graph, in which case each calculated quantity will require a column. A typical blank table of results is shown below. In this table, \( l \) and \( t \) are measured directly; readings of \( t \) have been repeated (to give \( t_1, t_2 \) and the average value \( t_{AV} \)); and the graph is one of \( l \) against \( T^2 \) (where \( T = 10T \)) so a column has been provided for the calculated quantity \( T^2 \).
Students should be discouraged from recording their data initially on a rough piece of paper and transferring it later onto a 'neat' copy of the table of results, because this introduces copying errors, wastes time, and runs the risk that the rough piece of paper will be lost.

It is good practice to carry out just one "dry run" of collecting a set of readings before actually beginning work. The advantage of this is that it will give students a feel for the problems and will allow them to make an informed decision about which readings, if any, should be repeated.

The column headings should show the quantity and the unit, as in the example above. These should normally be separated by a solidus (slash). No units should be shown beside the values in the body of the table.

Within each column of raw data, the degree of precision should be consistent. For example, if \( l/\text{cm} \) in the table above could be measured to the nearest 1 mm, then all the values in the column should be given to the nearest millimetre. This may mean that the number of significant figure is not consistent: the values might, for example, range from 68.4 cm to 8.7 cm.

In calculated quantities, the number of significant figures should be appropriate for each value, given the number of significant figures in the raw data from which they are calculated. Since the number of significant figures may vary within a column of raw data, it follows that it may also vary within a column of calculated data.

Most physics practical work requires that data is displayed on a graph, and the graph is usually (although not always) a straight line graph. Students need to know how to plot graphs correctly. However, if they are to be successful at evaluation and planning, they also need to have a clear understanding of why graphs are plotted. This may be taught by providing some data and facilitating a discussion among the students.

For example, this could be taught using the example of an experiment to determine the spring constant \( k \) of a spring from the equation \( F = kx \), where \( F \) is the force and \( x \) is the extension.

Start with a single reading of \( F \) and a single reading of \( x \), and calculate \( k \). Ask whether that is enough data, and establish that more data will minimise the effects of any aberrant readings.

Then provide several sets of readings, calculate \( k \) for each set separately, and find the mean value of \( k \). Discuss whether this is a good way to find \( k \). Establish that the aberrant reading, if there is one, has still contributed to the answer. Think about the limit of proportionality and how you would know whether or not it has been exceeded.

Plot a graph of \( F \) (y-axis) against \( x \) (x-axis). Find the gradient and show that it should be equal to \( k \). Point out how easy it is to spot (and discount) any data that is aberrant or beyond the elastic limit. Discuss how the data would have looked on the graph (and how the gradient would have been affected) if there had been a systematic error (for example, if the mass hanger’s mass had been 120 g when it should have been 100 g).
Conclude that plotting a graph and taking the gradient is a way of:

- averaging the data so that the effects of random errors are minimised;
- identifying aberrant points (which should be investigated further);
- eliminating some systematic errors;
- checking that the shape of the graph is as it should be.

The data for this lesson could be collected from real apparatus in a demonstration, with the whole class processing and discussing the data. If the mass of the mass hanger is adjusted to produce a systematic error in the data, so much the better. There is no need to introduce aberrant readings or to exceed the elastic limit of the spring: it is enough that these points can be checked on the graph.

There are a number of conventions to be followed in the plotting of graphs, and students need to learn these. These include:

- labelling of axes (these should be clearly labelled in the same way as the column headings in the table of results, with the quantity and the unit, and the values on the scale should be marked at frequent intervals);
- choosing scales that are easy to read (so awkward ratios such as 3, 5, 6, 7 or 9 squares per unit should be avoided);
- choosing scales that spread out the data points (i.e. so that the data is spread across at least half of the width of the graph paper and across at least half of the height. This may mean that a false origin has to be used, i.e. the point (0,0) is not shown on the page);
- plotting all of the data accurately;
- drawing a best-fit straight line through the points (when the points lie in a straight line) (there should be the same number of points above and below the line, and in each half of the line there should be the same number of points above it and below it);
- being neat (small crosses drawn with a sharp pencil for the data points; a thin best-fit line drawn with a sharp pencil and a clear plastic ruler: neat work allows the accuracy of the work to be checked);
- reviewing the data (the graph allows the data to be reviewed to see whether any of the points are anomalous and whether the expected trend is observed. Anomalous readings should always be checked, to see if there is an error in the plotting or in the readings).

The skills of presenting data in tables and on graphs should be seen as a developing set and something that students will improve with as they gain confidence and experience during the course. This will mean trying to choose practicals and activities that have a relatively contained, uncomplicated set of results in the early stages of the course and then working up to more complicated sets. Many students find that having a brief checklist helps them while they are still struggling to learn how to draw graphs, and the checklist also serves as a useful revision tool later on.

**Teaching students to analyse data and draw conclusions**

The analysis of data in AS level practical work can take a variety of forms, including:

- estimating uncertainties in measured quantities and converting between actual and percentage uncertainties;
- finding the peak value of a curve or reading specific values from a graph.
• finding the gradient and \( y \)-intercept of a graph;

• relating a straight line graph to a formula in the form \( y = mx + c \) to enable the values of constants to be determined;

• relating a graph or a set of data to a formula to conclude whether the data supports or contradicts the formula;

• using data to suggest whether or not two quantities are proportional;

• using data to formulate a hypothesis.

Students will need to be taught specifically and directly how to find the gradient and \( y \)-intercept of a graph. Whenever they calculate gradients, students should be encouraged to draw a triangle on their graph from which they can read values of \( \Delta y \) and \( \Delta x \) (and which you can use when checking through their work). They should be asked to think about the precision with which they can read \( \Delta y \) and \( \Delta x \) if the triangle is very small and very large, and should be led to the conclusion that the triangle should be as large as possible. It is the usual practice in examinations to require that the triangle spans at least half of the length of the line drawn, and this point can be emphasised to students. The most common mistakes that students make when calculating gradients are:

• using a small triangle;

• drawing the triangle between two data points instead of two points on the line of best fit;

• calculating \( \Delta x / \Delta y \) instead of \( \Delta y / \Delta x \).

Students need to be told what the term "\( y \)-intercept" means. Once they know this, they do not usually have great difficulty in reading the \( y \)-intercept directly from a graph. However, they do find it more difficult to determine the \( y \)-intercept where a false origin has been used or where the line of best fit goes through the top or bottom of the page before it reaches the \( y \)-axis. They need to be shown how to substitute the co-ordinates of one point \((x, y)\) on their line, plus their value of the gradient \( m \), into the equation \( y = mx + c \) in order to find the value of the \( y \)-intercept \( c \). It is a common mistake to use one of the data points instead of the co-ordinates of a point on the line in this substitution, and students should be shown that this gives an incorrect answer.

Technically, the gradient and \( y \)-intercept on a graph are numbers and have no unit. Students should not, therefore, be asked to give the units. However, the gradient and \( y \)-intercept may be numerically equal to constants which do have units. Students need to know that, in such cases, the units should be derived from the labelling of the axes on the graph.

The techniques for finding the gradient and \( y \)-intercept need to be explained to students first in a classroom setting, and then reinforced with a series of pen and paper exercises using sets of data provided. After this, they should be reinforced by providing practical work that includes the use of graphs.

Students often find it difficult to rearrange a given formula into the form \( y = mx + c \), and to relate this to the graph that they have plotted. For example, in a falling ball experiment, they might be told that \( g = 2hi^2 \) and asked to find the value of \( g \) from a graph of \( h \) (\( y \)-axis) against \( t^2 \) (\( x \)-axis). They need to be shown that, with \( h \) on the \( y \)-axis and \( t^2 \) on the \( x \)-axis, the formula has to be rearranged into the form \( h = mt^2 + c \). From this, they should be able to reach the equation \( h = \frac{1}{2}gt^2 \) and hence realise that the gradient is numerically equal to \( \frac{1}{2}g \) and that the \( y \)-intercept should be zero. After they have worked through an example like this in open class discussion, they should then be given several similar examples to work on to reinforce the skill. After this they should be equipped to use this skill when they encounter it in practical work.
The ability to manipulate formulae and to relate them to graphs is an important foundation stone for some of the planning and data analysis skills that students will encounter in their A2 course. You may need to check that students continue to practice this skill, and to provide some remedial exercises if necessary.

Students will need to be shown how to convert between percentage errors and actual errors, and opportunities should be found periodically to put this into practice in practical work. This can be done, for example, by asking them to consider which of their measurements has the largest percentage error. Similar questions can be included in the worksheets for most experiments. Identifying significant sources of error is an important skill both because it informs students’ decisions about which readings should be repeated and because it is a useful first step in the evaluation of the experimental procedures.

Teaching students to evaluate procedures

Students need to have a good understanding of experimental procedures before they can begin to be confident in evaluation. This understanding should include both a familiarity with a range of practical techniques and apparatus and a good grasp of the reasons why experimental procedures are carried out in particular ways. For this reason, evaluation procedures are best introduced in the second half of the AS year, after the other AS skills have been taught and practised.

The evaluation of very precise well-designed experiments can be difficult for students. With no significant sources of error and no major faults in the procedures used, students find it difficult to know what to write. When teaching evaluation skills, it is kinder to provide experiments which include significant sources of error, weaknesses in the method used to analyse the data, and plenty of scope for improvement.

It is sometimes suggested that students can evaluate experimental procedures without having carried them out. This is nearly always an unreasonable expectation. Some of the evaluation usually involves particularly difficult measurements, such as a length that is not easily accessible with a rule. Unless students have grappled with taking the measurement, they will have great difficulty in visualising the problems. Students need to do an experiment before they evaluate it.

Initially, students can be asked to estimate the actual error in the measurements they make and to convert this into a percentage error. In this way they can be asked, as a matter of routine, to identify the largest sources of error in the experiment. They should also be taught the difference between random and systematic errors and encouraged to check for systematic errors in their measurements.

From this starting point, students can begin to use checklists to help them to think about the limitations in an experiment. The checklist could include the following questions.

- Apart from the variables being measured, was there any other factor that might have affected the results?
- Which measurements were difficult to make?
- What were the largest sources of error?
- Were there any systematic errors?
- Was enough data collected?
- Was the range and distribution of the data points appropriate?
- Was a graph of the data plotted?

In each case, students should be asked not only to identify the limitations, but to suggest a way to improve the experiment. The improvements could range from suggesting the control
of variables to the use of more appropriate measuring instruments and to making measurements in a different way.

The checklist should be first introduced after the whole class has done the same experiment, even if this is a very short exercise. Responses to the checklist can be collected in a brainstorming session and then discussed so that students begin to get a feel for the sorts of suggestions that are appropriate to an evaluation. After this, students should be given regular opportunities to practise and develop their skills.

The practical work conducted after this point should not consist entirely of poorly-designed experiments which students can evaluate. Well-designed and precise experiments need to be interspersed with evaluation exercises so that students are given constant reminders of good experimental practice.

In their evaluations of the procedures followed in experiments that the students have carried out for themselves, repeating readings should not be regarded as an appropriate response. The reason is that, if it was appropriate to repeat readings, then this should have been done when the experiment was carried out. In the context of a demonstration, however, it might be necessary to accept this point!

As a rough rule of thumb, six data points is usually sufficient to provide a good straight line graph, but more data would nearly always improve the reliability of an experiment. When designing a practical for students to evaluate, it is a good idea to ask them to collect just two or three sets of data, and to omit the plotting of a graph. This provides opportunities for students to identify limitations and to suggest improvements. The checklist should help students to spot these particular weaknesses.

Whenever a class experiment has been carried out, it can be of great value for the whole class to discuss the limitations and sources of error. As well as being a useful tool to encourage class discussion, it creates a very simplistic ‘peer review’ model from which parallels can be drawn with professional scientific enquiry.
Designing a practical course for the AS year

This booklet is designed as a guide to help and support teachers in the delivery of the course. It does not provide a complete course on its own and does not offer full coverage of every aspect of the syllabus in detail. Instead, it is intended to help equip teachers to plan and deliver a full, coherent course. It is intended to complement the resources and experience already existing in the Centre.

Appendix 1 of this booklet provides a list of suggested practical activities that could be used to help deliver a Physics practical course at AS level. They are only suggestions: some of them may not be suitable for your centre and so you may need to adapt them or select alternatives.

The activities in Appendix 1 are listed in syllabus order, that is, in the order in which the subject content (not the practical skills) are listed in the syllabus. The actual order in which these practical activities are carried out will depend largely on the sequence in which the theory is taught, so that theory and practical work support each other in the learning process. When considering an order for the practical activities, you will also have to consider the sequence in which you are introducing new practical skills and techniques. Some of the activities will need careful adaptation to ensure that they only require the skills that have already been introduced and that they include the practical skills that you want to reinforce at that time.

For each practical activity, it is suggested that the following documents are produced:

- a student worksheet (to tell the student what to do);
- teaching notes (specifying the objectives of the activity);
- technical notes (specifying the apparatus, materials and facilities required).

As examples of how practical activities can be worked up in this way, Appendix 2 takes ten of the practicals from Appendix 1 and provides all three documents for each. The intention of Appendix 2 is that it should demonstrate to teachers how practical activities may be worked up and equip them to do the same for the whole of their AS level practical course.

Planning the course

The skills and techniques required of students are clearly laid out in the syllabus. When putting together a practical course, the syllabus should be used as a guide to ensure that the skills and techniques are all covered on at least one occasion (and hopefully more often).

When planning and preparing a course of lessons for the year, it is important to try and make sure that relevant practical activities are connected to the theory lessons and not just seen as an add-on. Practical work has a much greater strength if it is seen to complement and support the theoretical work covered in other lessons. Some practical skills may be introduced in one lesson and then developed or used in another lesson, building into a sequence. This helps to provide continuity for the students and to reinforce their learning.

By planning in advance it will be possible to select activities that run parallel with the content from the syllabus being delivered as well as providing a variety of different types of lesson. This will help to maintain students’ interest and motivation.

When a practical activity requires a new skill, technique or piece of equipment, time needs to be set aside for this. This may mean that an extra activity needs to be included at the start of the lesson to prepare the students in advance. Alternatively it may be more appropriate to allow for extra time and support during that particular activity.
Using past exam papers

Past papers are available from CIE and can form a useful part of final exam preparation. They often touch on content from the syllabus but do not always deal with it as directly as the examples in Appendix 2. They are therefore of limited use as practicals intended to complement the teaching of theory. In addition, they usually require a high degree of familiarity with the full range of practical skills. As such, if students are not totally confident with their skills and knowledge they will be unlikely to able to gain the full benefit from them.

Past exam papers should be seen less as a teaching tool but more as a valuable resource to be used towards the end of the course as part of a structured revision program. They have a role to play in the reinforcement of the practical skills that have been covered and in the final preparation for the examination.

Planning lessons and teaching the course

In the teaching notes section of each practical activity in Appendix 2, there are detailed notes including clearly highlighted ‘key learning objectives’. It is important that these objectives are stressed when the activity is being introduced and described to the students. Many students can carry out practical activities without fully understanding what they are doing and why they are doing it, and this inhibits their ability to learn from the experience. It is usually worth explicitly stating the key learning objectives to the students so that they have a clear focus for the lesson.

Although students will be involved in practical activity for most of the lesson, some lesson time should be spent on ensuring that each activity is properly introduced. The way an individual lesson is structured is very much up to the individual teacher but below is one possible approach to teaching practical activities.

Introduction (10 mins)

A teacher-led oral presentation which includes:

- An explanation of the activity that is to be carried out.
- A recap or explanation of the theory that relates to the practical. In many cases this will have been covered in more detail in a previous lesson.
- A description (and possibly a demonstration) of any equipment that is to be used or is needed in the practical. It is easy to make assumptions about what the students are confident with and this provides an opportunity to check before they start. If a new piece of equipment is to be used then the skills needed to use it must be directly taught. This may be done at this point but in some cases it is better to have provided a dedicated session at an earlier time.
- Safety. This should be raised before every single practical regardless of the risk. Students can be asked to make the risk assessment themselves and to make suggestions as to appropriate precautions although each practical must have been risk assessed by a teacher beforehand.

Preparation (5 – 10 mins)

Students should be encouraged to prepare before starting to take readings. As well as setting up the apparatus, they should also be encouraged to make one ‘dry run’ of a set of readings. They should consider the range of readings to be taken and whether repeat readings are needed. They should prepare the outlines of their tables of results.
Main activity (35 – 60 mins)
Each of the practical activities will take different amounts of time depending upon the students involved and the nature of the task. During this time some groups may well need support and help.

Plenary (5 – 10 mins):
A teacher-led session where the main threads of the practical are brought back together. Some of the areas covered could include:

- A recap of the theory that underlies the activity and a reminder to cross-reference the practical work and the theory notes.
- A discussion of the practical skills and any particular equipment or techniques that were needed.
- A discussion of any limitations, errors or problems involved in the activity and ways in which these could be dealt with.
- A reminder of the expectations of the written work that will follow (which should be included in the student worksheets).

Planning for a circus
In many Centres, practical activities may be carried out as part of a circus. In this case it is not possible for an introduction to the activities to be held as a teacher-led plenary session at the start of each lesson, because there are too many activities taking place. However, the introduction of each activity is important and should not be lost: it helps the students to understand both what they are doing and why they are doing it. One possible solution to this is to hold a ‘circus introduction session’.

For the first session of the circus, set up the laboratory so all the equipment for each of the activities is visible. Take the whole class round the laboratory introducing each experiment, using the introduction section above as a guide. Although this may take quite some time, this is a worthwhile thing to do and will hopefully allow each subsequent practical session to run more smoothly. It will give students a clearer idea of what they are required to do.

A possible alternative to this would be to run the first session without introducing the experiments. Give the students a very quick run-through and then issue the student worksheets. Let students know that, at the beginning of the next session, they will need to describe the key points to the rest of the class. Begin the next session with each group introducing to the rest of the class the activity they have done. If this approach is taken then this can act as a good way to get the students to develop their communication skills.
## Appendix 1: Possible AS practical activities

The table below lists a series of practical activities that can be delivered to both support the theory and to develop the students' practical skills. The activities are mapped against the learning outcomes in the theory sections in the syllabus and are listed in syllabus order.

Each practical activity should also be mapped against the practical skills required, partly to ensure that the skills and equipment are introduced at the correct points and partly to ensure that all skills are covered during the course. Many of the practical activities could be conducted in different ways to give emphasis to different skills, and therefore the mapping must be done when the details of the practical are worked out (i.e. when the student worksheets, teaching notes and technical notes are produced).

Suggestions have been made whether something is suitable as a demonstration or practical. In almost all cases it is possible for students to carry out experiments listed as demonstrations, although the experiments may need to be set up and tested beforehand.

<table>
<thead>
<tr>
<th>Practical Name</th>
<th>Description / comments</th>
<th>Suitability for practical or demonstration</th>
<th>Link to syllabus learning outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal velocity</td>
<td>Detailed in Appendix 2.</td>
<td>Practical</td>
<td>3(b), 3(d), 3(j), 5(c)</td>
</tr>
<tr>
<td>Measuring speed and acceleration</td>
<td>Using ticker timers or data-logging equipment, and trolleys or a linear air track, the motion of objects moving at constant speed or with constant acceleration can be analysed. The experiments should be set up so that students can collect data that can be used to plot motion graphs which they can analyse.</td>
<td>Practical</td>
<td>3(b), 3(d), 3(e), 3(g)</td>
</tr>
<tr>
<td>Acceleration down a slope</td>
<td>Detailed in Appendix 2.</td>
<td>Practical</td>
<td>3(g)</td>
</tr>
<tr>
<td>Practical Name</td>
<td>Description / comments</td>
<td>Suitability for practical or demonstration</td>
<td>Link to syllabus learning outcomes</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Measurement of $g$ with falling object</td>
<td>A millisecond timer is connected to two switches, as the ball is dropped the timer starts. When it has fallen a certain distance it triggers the second switch and stops the timer. Using Newton’s laws $g$ can be calculated. Alternatively this experiment could be carried out with data-logging equipment or ticker timers.</td>
<td>Practical or demonstration</td>
<td>3(g), 3(i)</td>
</tr>
<tr>
<td>Force, mass and acceleration</td>
<td>An object is accelerated with a known force. The relationship between force and acceleration can then be analysed graphically and the mass of the system found. This is often done by accelerating trolleys along a bench with a known weight on the end of a pulley hanging over the edge. The acceleration is recorded (directly or indirectly) by data loggers or a ticker timer for different accelerating forces. Elastic bands can be used to apply the force but this will only allow the identification of a linear relationship between force and acceleration.</td>
<td>Practical</td>
<td>4(a), 4(b), 4(f)</td>
</tr>
<tr>
<td>Practical Name</td>
<td>Description / comments</td>
<td>Suitability for practical or demonstration</td>
<td>Link to syllabus learning outcomes</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Conservation of momentum</td>
<td>An experiment to investigate the law of conservation of momentum. This is commonly done with two mechanics trolleys or two vehicles on a linear air track (although freely running toy cars can be used). Both their velocities are measured by ticker timer, data logger or other method before and after any collision. Various collisions are carried out and each time the momentum before and after the collision can be calculated from the masses and velocities and from this the law can be verified. Investigations into elastic and inelastic collisions can also be carried out.</td>
<td>Practical</td>
<td>4(h), 4(d), 4(i), 4(j)</td>
</tr>
<tr>
<td>Weight and upthrust</td>
<td>A known mass is hung on the end of a newton meter, this is then lowered into a beaker of water (or other fluid) and the changes in the reading on the newton meter are recorded as the object is immersed. The experiment can be extended by placing the whole experiment on a top-pan balance and observing the change in reading on that at the same time.</td>
<td>Practical or demonstration</td>
<td>5(b)</td>
</tr>
<tr>
<td>Triangle of forces board</td>
<td>Detailed in Appendix 2.</td>
<td>Practical</td>
<td>5(d)</td>
</tr>
<tr>
<td>Finding the mass of a metre rule using the principle of moments</td>
<td>Detailed in Appendix 2.</td>
<td>Practical</td>
<td>5(i), 5(e)</td>
</tr>
<tr>
<td>Practical Name</td>
<td>Description / comments</td>
<td>Suitability for practical or demonstration</td>
<td>Link to syllabus learning outcomes</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>----------------------------------------------------------------------------------------</td>
<td>-------------------------------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Finding the densities of different materials</td>
<td>Detailed in Appendix 2.</td>
<td>Practical</td>
<td>9(a)</td>
</tr>
<tr>
<td>Structure of metals</td>
<td>The crystalline nature of the structure of metals can be shown by looking at prepared samples under a microscope. Alternatively if a galvanized metal bucket or similar is available then it is often possible to see the crystal grains clearly with the naked eye. Sometimes the surface needs a light clean in order to show the grains clearly.</td>
<td>Demonstration</td>
<td>9(e)</td>
</tr>
<tr>
<td>Changes of state (boiling)</td>
<td>If water is heated with a constant source of energy input (electrical heater or Bunsen flame) and the temperature is recorded it is possible to demonstrate graphically that at the change in state from liquid to gas there is no change in temperature whilst energy is still being supplied to the system. The water needs to be constantly stirred and care needs to be taken that the container does not boil dry. Data-logging equipment could also be used to investigate evaporation and the energy changes involved.</td>
<td>Practical or demonstration</td>
<td>9(i)</td>
</tr>
<tr>
<td>Elasticity and springs</td>
<td>Detailed in Appendix 2.</td>
<td>Practical</td>
<td>10(b), 10(f)</td>
</tr>
<tr>
<td>Finding the Young modulus of a wire</td>
<td>Detailed in Appendix 2.</td>
<td>Practical</td>
<td>10(c), 10(d)</td>
</tr>
<tr>
<td>Practical Name</td>
<td>Description / comments</td>
<td>Suitability for practical or demonstration</td>
<td>Link to syllabus learning outcomes</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Material failure</td>
<td>Samples of various materials can be examined under a microscope in order to illustrate their structures. Students could discuss whether they felt that the failure was brittle or ductile. Samples could include the wire used in the Young modulus experiment, a piece of acrylic that has been snapped, a piece of broken glass or spaghetti.</td>
<td>Practical or demonstration</td>
<td>10(g)</td>
</tr>
<tr>
<td>Measuring the frequency of a sound in air</td>
<td>A loudspeaker is connected to an audio-frequency signal generator and a note is produced. A microphone is connected to an oscilloscope and it is adjusted until a stable trace is shown. By adjusting the time base and x-shift knobs to get a good trace, a value for frequency can be calculated. Knowing the speed of sound in air will allow a value of wavelength to be calculated.</td>
<td>Demonstration</td>
<td>15(d), 15(j)</td>
</tr>
<tr>
<td>Practical Name</td>
<td>Description / comments</td>
<td>Suitability for practical or demonstration</td>
<td>Link to syllabus learning outcomes</td>
</tr>
<tr>
<td>----------------</td>
<td>-------------------------</td>
<td>------------------------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Measurement of the speed of sound in air using a dual-beam oscilloscope</td>
<td>A microphone is connected to a dual-beam oscilloscope. The other connection of the oscilloscope is connected to an audio-frequency signal generator and loudspeaker. Slowly move the microphone and observe the phase differences between the two traces. Measure the distance the microphone moves as the traces on the oscilloscope move from one in-phase position to the next in-phase position. This distance is the wavelength of the sound. Determine the frequency of the sound from the oscilloscope traces and use the equation $v = f\lambda$ to calculate the speed of sound.</td>
<td>Practical</td>
<td>15(d), 15(j), 15(b)</td>
</tr>
<tr>
<td>The relationship between sound intensity and distance</td>
<td>A loudspeaker is connected to an audio-frequency signal generator and a note is produced. A microphone is connected to an oscilloscope and it is adjusted until a stable trace is shown. By changing the distance between the microphone and the loudspeaker, the amplitude of the trace on the oscilloscope can be related to the sound amplitude and hence to intensity. Depending on the equipment and the acoustics this may not deliver high quality results. The inverse square law is outside the syllabus but the experiment can provide a useful open-ended investigation or an opportunity for evaluation.</td>
<td>Practical or demonstration</td>
<td>15(f)</td>
</tr>
<tr>
<td>Practical Name</td>
<td>Description / comments</td>
<td>Suitability for practical or demonstration</td>
<td>Link to syllabus learning outcomes</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Measurement of the speed of sound in air using stationary waves</td>
<td>A glass or plastic tube that is open at both ends with a half-metre rule attached to it is placed inside a larger container filled with water. A tuning fork of known frequency is struck and held just above the tube. The tube is then raised until the sound reaches a maximum loudness. The length of tube above water level is measured. This is then repeated for different tuning forks and a data set for frequency $f$ and length $l$ of tube is recorded. Analysis of the standing wave gives $\lambda = 4l$ and from this and $v = f\lambda$ the speed of sound can be calculated.</td>
<td>Practical</td>
<td>15(k), 15(d), 16(b)</td>
</tr>
<tr>
<td>Young’s slits</td>
<td>A laser beam is passed through a double slit (typically less than $\frac{1}{2}$ mm apart) and onto a screen several metres away. From measurements of the interference pattern, the wavelength of light may be calculated (if the slit separation is known) or the slit separation may be calculated (if the wavelength is known). It is possible to perform this experiment with a more conventional light source (ideally over 40W), lenses and slits. If this is the case then the distance to the screen is likely to need to be reduced in order to gain a visible pattern.</td>
<td>Practical or demonstration</td>
<td>16(g), 16(h), 16(i), 16(e)</td>
</tr>
<tr>
<td>Diffraction grating</td>
<td>A similar experiment to the Young’s slits experiment can be carried out with a diffraction grating.</td>
<td>Practical or demonstration</td>
<td>16(j), 16(i), 16(e)</td>
</tr>
<tr>
<td>Practical Name</td>
<td>Description / comments</td>
<td>Suitability for practical or demonstration</td>
<td>Link to syllabus learning outcomes</td>
</tr>
<tr>
<td>----------------</td>
<td>-------------------------</td>
<td>------------------------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Using an oscilloscope as a voltmeter</td>
<td>A very quick demonstration will involve connecting a cell or any d.c. supply to an oscilloscope and adjusting the controls to gain and measure a reading. Depending upon the oscilloscope it may be advisable to turn the time base off in order to make this demonstration more clear. A.c. power supplies can also be connected (with the time base on). This provides an excellent introduction to the oscilloscope and explaining what the controls do and how they can be adjusted.</td>
<td>Demonstration</td>
<td>19(d)</td>
</tr>
<tr>
<td>Measuring the resistivity of a wire</td>
<td>Detailed in Appendix 2.</td>
<td>Practical</td>
<td>19(h), 19(l)</td>
</tr>
<tr>
<td>Behaviour of a thermistor</td>
<td>A thermistor is connected to a digital multimeter able to read the resistance directly and is then placed in a beaker of water. The water is heated and the temperature measured. A set of temperature and resistance readings can be collected and a calibration graph for the thermistor plotted. The range of the data can be extended if ice is used. This can give students experience of selecting the appropriate scale on a multimeter as well as an introduction to calibration curves. The experiment could also be done using a battery or power supply and an ammeter or voltmeter (either or both of which could be digital multimeters).</td>
<td>Practical</td>
<td>19(j)</td>
</tr>
<tr>
<td>Practical Name</td>
<td>Description / comments</td>
<td>Suitability for practical or demonstration</td>
<td>Link to syllabus learning outcomes</td>
</tr>
<tr>
<td>----------------</td>
<td>------------------------</td>
<td>------------------------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Ohm's law</td>
<td>A simple circuit with a variable d.c. power supply, an ammeter, a voltmeter and a resistor can be used to investigate Ohm’s law experimentally and to determine the resistance. Readings should be taken for positive and negative values of p.d. In most cases this will just mean swapping the connectors of the resistor supply around. If standard meters are used, it is important to choose the resistor well in order to get a good set of readings. This is less of an issue if digital multimeters are used. Safety note: the resistor can get very hot, particularly if the resistance is low. A milliammeter and a 1 kΩ resistor will be suitable.</td>
<td>Practical</td>
<td>19(k), 19(h)</td>
</tr>
<tr>
<td>I-V characteristics of a filament lamp and a semiconductor diode</td>
<td>A simple circuit with a variable d.c. power supply, an ammeter, a voltmeter and a filament lamp can be used to plot the I-V characteristics of a filament lamp. The experiment can then be repeated using a semiconductor diode. The power consumption of each component at a specified voltage can be determined from the graphs.</td>
<td>Practical</td>
<td>19(i), 19(f)</td>
</tr>
<tr>
<td>Practical Name</td>
<td>Description / comments</td>
<td>Suitability for practical or demonstration</td>
<td>Link to syllabus learning outcomes</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>----------------------------------------------------------------------------------------</td>
<td>-------------------------------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Internal resistance of a dry cell</td>
<td>A simple circuit with a voltmeter, an ammeter, a dry cell and a variable resistor (suggested 10Ω to 100Ω) is set up. The resistance is varied and a set of readings for the p.d. across the cell and current in the circuit is collected. From this data the internal resistance can be determined from a graph of p.d. against current. The variable resistor and the internal resistance need to be of comparable resistance and it may be necessary to connect a fixed resistor in series with the dry cell in order to simulate a larger internal resistance than is actually present.</td>
<td>Practical</td>
<td>19(o)</td>
</tr>
<tr>
<td>Internal resistance of a potato cell</td>
<td>A similar experiment to the internal resistance of a dry cell can be carried out using a potato cell instead of the dry cell. The potato cell is constructed from a potato with zinc and copper sheet electrodes inserted into it. Similar cells can be constructed from most types of fruit or vegetable provided that it is moist inside.</td>
<td>Practical</td>
<td>19(o)</td>
</tr>
<tr>
<td>Practical Name</td>
<td>Description / comments</td>
<td>Suitability for practical or demonstration</td>
<td>Link to syllabus learning outcomes</td>
</tr>
<tr>
<td>------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>LDR and light intensity</td>
<td>An LDR is connected to a battery or power supply, an ammeter and a voltmeter so that its resistance can be calculated. The LDR is placed on the zero end of a metre rule which is pushed inside a thick cardboard tube with black paper around it. At the other end of the tube is a lamp. The LDR is moved towards and away from the lamp and resistance and distance are recorded. If the LDR has been calibrated beforehand (or if the manufacturer provides calibration details) then the variation of light intensity with distance can be investigated.</td>
<td>Practical</td>
<td>20(b), 20(k)</td>
</tr>
<tr>
<td>Potential divider</td>
<td>Detailed in Appendix 2.</td>
<td>Practical</td>
<td>20(j)</td>
</tr>
<tr>
<td>Measuring g using a pendulum</td>
<td>Detailed in Appendix 2.</td>
<td>Practical</td>
<td>-</td>
</tr>
</tbody>
</table>
Appendix 2: Examples of AS practicals

Each of the ten practical activities in this appendix consists of a student worksheet, teaching notes and technical notes. These have been printed on separate pages for ease of photocopying: teachers are welcome to photocopy these pages for use within their own schools.

It is assumed that students will, as a matter of course, be required to write a brief account with a diagram of the experimental arrangement. The worksheets do not make this requirement explicit.

In all cases, the practical activities could be adapted to allow for the fact that different schools have different apparatus available. Most may also be adapted to change the practical skills that are given emphasis. The intention, in this appendix, is to illustrate how an idea for a practical activity may be worked up into student worksheets, teaching notes and technical notes.