

Teaching A Level Biology Practical Skills

in preparation for 9700 paper 5

Your attention is drawn to the section on Risk Assessment on page 15 of the Introduction to this booklet, and to the hazards indicated in Appendices 1 and 2. While all effort has been made to ensure that appropriate safety indications are given, CIE accepts no responsibility for the safety of these experiments and it is the responsibility of the teacher to carry out a full risk assessment for each experiment undertaken, in accordance with local rules and regulations. Hazard data sheets should be available from your suppliers.

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Introduction

You may have been teaching AS and A level biology 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. Scientists 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 above those with a purely theoretical background. It is true that there are branches of biology that might be described as purely theoretical but they are in the minority. Essentially, biology is a practical 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?

Some of 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; but 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.

It is designed for the teacher rather than for the student. Its objective is to provide a framework within which the practical skills of teachers can develop and grow. Experience shows that as a teacher's practical skills grow, so too do the confidence to teach such skills and the time that you will be prepared to spend on teaching practical work.

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. Consider the weighting given to assessment objectives in the syllabus: 24% is allocated to experimental skills and investigations and 30% is allocated to handling, applying and evaluating information. Taken together, 55% of the total award is related to a students' ability to interpret data, understand how this has been obtained, recognise limitations and suggest explanations; all of which lend themselves to investigative work involving practical experience. If the specific practical papers are considered in isolation, they still represent 23% of the AS and 24% of the A Level award.

In planning a curriculum, teachers should therefore expect to build in time for developing practical skills. If, for example, the time allowed is 5 hours per week over 35 weeks, then a minimum of 1 hour per week should be built into the plan, so that over the year, a minimum of 35 hours is made available. Bearing in mind the emphasis on assessment objectives that related to information handling and problem solving, a minimum of 2 hours per week might be more appropriate, which at 40% of the time is still less than the overall weighting for these assessment objectives.

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 in the order in which practical exercises are used, as the skills practiced in these booklet are hierarchical in nature, i.e. the basic skills established in the AS booklet are extended and developed in the A2 Level booklet. Thus, students will need to have practiced basic skills using AS exercises before using these skills to tackle more demanding A Level 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/A2 exercises, still applies.

What resources will I need?

For a practical course in A-level Biology 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 lab. Alternative 'low-tech' exercises are also provided where possible.

A list of the basic resources required for assessment may be found in the syllabus. A more detailed list may be found in the booklet '*CIE Planning For Practical Science in Secondary Schools*', Appendix B.

Is there a limit to the class size?

It is true that 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 person can reasonably manage, both for safety reasons and so that adequate support can be given to each student. Larger numbers can more easily and safely be accommodated with input from another person with appropriate qualifications / experience or splitting the class 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 readers that practical work is an essential part of biology as a science and underpins the whole teaching programme, the aim 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 the practical classes. Students who enjoy what they are doing are likely to carry this enthusiasm with them and so be better motivated.
- Learning is enhanced by participation as students tend to remember activities they have performed more easily, thus benefiting 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.”
- Chemistry, physics and biology are by their very nature, practical subjects – 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. For all students, whether they regard themselves as scientists or non-scientists, the skills that they develop by doing practical work, hand-eye coordination skills, communication, numeracy and problem solving skills, will prove to be useful transferable skills throughout their future life.
- A practical course develops many cross-curricular skills including literacy, numeracy, ICT and communication skills. It develops the ability to work both in groups and independently and 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 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. While it could be argued that the required skills could be developed for papers 31 and 32 simply by practising past-papers, the all-round confidence in practical ability will be greatly enhanced by a wider experience. Similarly for paper 5, while it might be argued that planning, analysis and evaluation could be taught theoretically, 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 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 are much more likely to perform well than those with limited practical skills.

What are the practical skills required by this course?

This course addresses seven practical skills 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 / 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**

The syllabus shows how these seven skills are assessed and the structure is common to all three sciences. The emphasis of the AS syllabus is on developing an understanding and practice of scientific procedures, the collection of data, analysis and drawing conclusions. It also starts to develop critical evaluation of procedures by suggesting improvements to experimental procedures. In general students find the performance of practical procedures and the collection of data more accessible than analysis, whilst evaluation is least readily accessed. To enable access to these more demanding skills, students need to understand why an experimental procedure is carried out in a particular way so that they can recognise sources of error or limitations which could affect the reliability of their results. Students will not be able to evaluate until they can critically review a practical procedure.

The A2 syllabus builds upon the skills developed in AS and its emphasis is on the higher level skills of planning, analysis and evaluating. In order to plan effectively, students need to be able to evaluate procedures and critically assess results. This is best achieved by the performance of practical exercises starting in AS with relatively straightforward and familiar contexts and developed in A2 by the use of more complex procedures and less familiar contexts. Data analysis again develops from AS into more complex treatments so that students need to be given opportunities to gather suitable data and perform the appropriate manipulations. The evaluation of conclusions and assessing procedures are very high order skills. Students who have not had sufficient opportunity to plan and trial their own investigations will find these skills difficult. Students are not expected to be able to plan perfectly, but to recognise weaknesses and make reasonable suggestions for improvement. The best learning tool to develop these skills is to devise a plan, carry out the investigation and then assess how well the planned procedure worked. The syllabus gives detailed guidance on the expected skills and learning outcomes.

In summary, as the syllabus clearly shows, skills 2-6 listed above will be assessed at AS level in papers 31 and 32. Skills 1 and 7 will only be assessed at A level in paper 5, which will also take skills 5 and 6 to a higher level.

The above list shows the seven skills in the order in which they would be used in an extended investigation. It is not suggested, nor would it be wise, to teach these skills in this order. 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 skill 2, initially with very simple tasks and paying attention to the establishment of safe working practices.

Once a measure of confidence in their manual dexterity has been established, AS students can move on to exercises that require skills 3 and 4 to be included. Extensive experience in carrying out practical procedures allows students to gain awareness of appropriate quantities and become more organised in time management 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 frequent and inappropriate response. If students are to master this skill, they need to develop an appreciation of reliability and accuracy inherent in the equipment and procedure they are using. Only then will they be able to identify anomalous results, or results which fall outside of the 'range of uncertainty' intrinsic in

the choice of apparatus used and so are considered to be inaccurate. Exercises with less reliable/accurate outcomes can be used to provide more scope for the evaluation of procedural, technique or apparatus 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 in Paper 5. Unless students use apparatus they do not develop an understanding of how it works and the sort of measurements that can be made using particular sorts of apparatus. 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.

The evaluation of conclusions, skill 7, is done by comparison of the outcome of an exercise with the predicted outcome, and so is also an A2 skill. It should be taught and practised as part of the planning exercises.

Summary of each of the 7 skills

Full details of the requirements for each of these skills may be found on pages 34 to 41 of 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. They should use their knowledge and understanding of the topic under consideration to make a quantitative, testable, prediction of the likely outcome of the experiment.

- **Methods**

The proposed experimental procedure should be workable. It should, given that the apparatus is assembled appropriately, allow data to be collected without undue difficulty. There should be a description, including 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, and quantities to be used should be specified. The use of control experiments should be considered.

- **Risk assessment**

Candidates 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.

- **Planning for analysis, conclusions and evaluation**

Students should be able to describe the main steps by which their results would be analysed in order that valid conclusions might be drawn. This may well include the generation of a results table and the proposal of graphical methods to analyse data. Also, they should propose a scheme for the interpretation and evaluation of the results themselves, and of the experimental procedure employed in obtaining those results. There should

be an indication of how the outcomes of the experiment would be compared with the original hypothesis.

2 Setting up / manipulating apparatus

It is important that students are allowed sufficient time and opportunity to develop their manipulative skills to the point where they are confident in their approach to experimental science. They 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.

3 Making measurements and observations

- **Measuring/observing**

Whilst successfully manipulating the experimental apparatus, it is crucial that students are able to make measurements with accuracy and/or to make observations with clarity and discrimination. Accurate readings of meters or burettes and precise descriptions of colour changes and precipitates will make it much easier for students to draw valid conclusions, as well as scoring more highly in the test.

- **Deciding on what measurements/observations to make**

Time management is important, and so students should be able to make simple decisions on the number and the range of tests, measurements and observations that can be made in the time available. For example, if the results of the first two titrations are in good agreement, there is no need to carry out a third.

Students need to be able to make informed decisions regarding the appropriate distribution of measurements within the selected range, which may not always be uniform, and the timing of measurements made within the experimental cycle. They should also be able to identify when repeated measurements or observations are appropriate.

The strategies required for identifying and dealing with results which appear anomalous should be practised.

4 Recording and presenting observations and data

An essential, but frequently undervalued, aspect of any experimental procedure is the communicating of the results of the procedure to others in a manner that is clear, complete and unambiguous. It is vital that students are well practised in this area.

- **The contents of the results table**

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 column headings in a results table**

The heading of each column must be clear and unambiguous. In columns which are to contain numerical data, the heading must include both the quantity being measured and the units in which the measurement is made. The manner in which this information is given should conform to 'accepted practice'.

- **The level of precision of recorded data**

It is important that all data in a given column is recorded to the same level of precision, and that this level of precision is appropriate for the measuring instrument being used.

- **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.

- **Significant figures**

Students should be aware that the number of significant figures to which the answer is expressed shows the precision of a measured quantity. Therefore, great care should be taken with regard to the number of significant figures quoted in a calculated value. The general rule is to use the same number of significant figures as (or at most one more than) that of the least precisely measured quantity.

- **Data layout**

Students should be able to make simple decisions concerning how best to present the data they have obtained, whether this is in the form of tabulated data or as a graph. When plotting graphs they should be able to follow best practice guidelines for choosing suitable axis scales, plotting points and drawing curves or lines of best fit. In drawing tables they should be able to construct a table to give adequate space for recording data or observations.

5 Analysing data and drawing conclusions

This skill requires students to apply their understanding of underlying theory to an experimental situation. It is a higher-level skill and so makes a greater demand on a student's basic understanding of the biology involved. Even when that understanding is present, however, many students still struggle. The presentation of a clear, lucid, watertight argument does not come naturally to most people and so much practice in this area is recommended.

- **Interpretation of data or observations**

Once data has been presented in the best form for analysis of the results of the experiment, the student should be able to describe and summarise any patterns or trends shown and the key points of a set of observations. Further values such as the gradient of a graph may be calculated or an unknown value found, for example from the intercept of a graph.

- **Errors**

Students should be used to looking at an experiment, assessing the relative importance of errors and where appropriate, expressing these numerically. Students should be aware of two kinds of error.

- i The 'error' that is intrinsic in the use of a particular piece of equipment. Although we refer to this as an equipment error, we really mean that there is a 'range of uncertainty' associated with measurements made with that piece of equipment. This uncertainty will be present no matter how skilled the operator might be.

- ii Experimental error, which is a direct consequence of the level of competence of the operator or of the effectiveness of the experimental procedure.

- **Conclusions**

Students should learn to use evidence to support a given hypothesis, to draw conclusions from the interpretation of observations, data or calculated values and to make scientific explanations of their data, observations and conclusions. Whatever conclusions are drawn, they must be based firmly on the evidence obtained from the experiment. At the highest level, students should be able to make further predictions and ask appropriate questions based on their conclusions.

6 Evaluating procedures

Arguably, this is one of the most important, and probably one of the most difficult skills for a student to develop. In order for the evaluation to be effective, students must have a clear understanding of the aims and objectives of the exercise, otherwise they will not be able to judge the effectiveness of the procedures used. They must be able to evaluate whether the errors in the data obtained exceed those expected due to the equipment used. If this is the case, they then need to identify those parts of the procedure which have generated these excess errors, and suggest realistic changes to the procedure which will result in a more accurate outcome. Students should also be able to suggest modifications to a procedure to answer a new question.

The evaluation procedure may include:

- i the identification of anomalous values, deducing possible causes of these anomalies and suggesting appropriate means of avoiding them,
- ii an assessment of the adequacy of the range of data obtained,
- iii an assessment of the effectiveness of the measures taken to control variables,
- iv taking an informed judgement on the confidence with which conclusions may be drawn.

7 Evaluating conclusions

This is also a higher-level skill, which will demand of the student a thorough understanding of the basic theory that underpins the science involved.

The conclusions drawn from a set of data may be judged on the basis of the strength or weakness of any support for or against the original hypothesis.

Students should be able to use the detailed scientific knowledge and understanding they have gained in theory classes in order to make judgements about the reliability of the investigation and the validity of the conclusions they have drawn.

Without practice in this area, students are likely to struggle. In order to increase the confidence in drawing conclusions, it is recommended that practical exercises, set within familiar contexts, be used to allow students the opportunity to draw conclusions, make evaluations of procedure and assess the validity of their conclusions.

In the examination, students may be required to demonstrate their scientific knowledge and understanding by using it to justify their conclusions.

Ways of doing practical work

Science 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, particularly in rapidly developing fields such as biotechnology. In these new areas of science, teachers will often find themselves leading practical work that they have not had the chance experience themselves as students.

Other practical activities should offer the students the opportunity to devise their own methods or to apply to solving a problem the methods that they have been taught. The excitement generated by exposure to “new” and unfamiliar techniques 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, introducing catalysis by experimentation, followed up by theoretical consideration of the reasons for the unexpected 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 the limiting factors of photosynthesis with a series of practicals investigating the effect of light intensity and hydrogen carbonate concentration on photosynthesis in water weed. In all cases, learning will be enhanced most effectively by practical work that encourages students to be involved, to think, to apply and use their knowledge, understanding and skills.

Practical work does not always have to be laboratory based. In classrooms, the use of models, role play and paper cut outs to simulate processes can be equally valuable. Field studies also contribute greatly to a students’ appreciation of Biology. No amount of reading or viewing videos can substitute for being exposed to an environment and the organisms living there. Even a carefully managed environment like a school lawn represents a challenge to recognise the species and to understand how they can survive.

There are a variety of strategies by which practical work can be integrated into a scheme of work. Teachers should use a variety of methods, enhancing a variety of subject specific skills and simultaneously developing a variety of transferable skills that will be useful throughout their future professional lives. Some of the ways of delivering practical work also enable the teacher to interact on a one-to-one basis with individual students. This allows a teacher to offer support at a more personal level and develop a greater awareness of an individual students needs.

Your 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 your students, availability and expertise of technical support, the time available, your intended learning outcomes for the activity and safety considerations. The following are some possible strategies for delivery of practical work:

- **Teacher demonstrations**

These require less time than a full class practical, 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.

Considerations in choosing to do a 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.
- 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 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 utilising limited resources or managing investigations that test a range of variables and collect a lot of measurements. Although the same procedure may be performed, each student group collects only one or a few sets of data which are then pooled. For example, if five concentrations of the independent variable are being tested, each of which need to be measured at two minute intervals for thirty minutes, then a group of five students can each test one concentration. Field studies also lend themselves to group activities as a lot of data has to be collected in a short period of time. 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 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** – this could be a serious issue and 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 on 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. Most commonly, during a lesson a number of short activities are 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, to maintain a safe environment. In these situations it is useful to have at least two 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.

- i **Apparatus** – if the amount 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. It can also be used to access parts of the syllabus that have little laboratory based investigation. For example, in gene technology students might use internet based research to find examples of genetic modification and present a poster display showing the implications. Another might be in aspects of human reproduction, where research into the control of human reproduction and look at trends in access to contraception or IVF together with ethical considerations. 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 outside the class room. Care is needed in selecting the topics and setting a time scale, so that the relevance is maintained to the syllabus context. The work can be directed at the production of posters, presentations to give to the group or reports from the group or individual.

- **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 lab 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. After school clubs could be vehicle for project work that is related to science and of social or economic importance, for example, endangered species. Students who do attend the club could be used as a teacher resource by bringing back their finding to a class room session.

Keeping records

Students often find it a problem to integrate the practical work to the theory. This is particularly true when a series 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 chemicals are spilled on them. One important criterion is that students are trained to immediately and accurately record results.
- Practical procedures may be provided, or students write their own notes from a teacher demonstration. These may be lost, so 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 work 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 lose items. Exercise books can be used but students should be encouraged to glue provided protocols 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 note and other items from 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 as something 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, but 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,
- thought should be given to the seasonal availability of materials such as organisms or specific stages of organisms, and the sometimes short shelf-life of thermo-sensitive substances such as enzymes or hygroscopic substances such as some salts
- the time taken from order to delivery, potential for damage during despatch and cost of materials to be obtained from local, national or international 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 chemicals, electricity, growing microorganisms etc. There may also be

regulations controlling use of controversial materials such as genetically modified organisms.

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, which is one reason for the existence of this booklet. It is better to get going and 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.

- Decide on the aims of the work – the broad educational goals, in terms of the broad skill areas involved (e.g. planning) and the key topic areas (e.g. animal transport systems or unfamiliar material)
- Consider the investigative skills being developed. Reference should be made to the syllabus, which in the practical skills section, includes learning outcomes relating to practical skill. In the 2007 syllabus these are identified by bullet points, but from 2008 onwards, alpha-numeric identifiers will be used. 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 transport learning outcomes will be achieved? In a few 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 9700 syllabus at all may be used for AS or A2 practicals.
- In addition, it may be 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 work sheet. 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 helpful to ask students or another teacher to read work sheets before they are finalised as they can identify instructions that are ambiguous or 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 (see below) before any preparatory practical work is done, and certainly well before students do any of the practical work. You should consider
 - the likelihood that any foreseeable accident might occur – for example, pupils putting glass tube through bungs are quite likely to break the tube and push it though their hand

- the potential severity of the consequences of any such accident – for example dropping onto a desk a plastic dropper bottle of 0.01 mol dm^{-3} hydrochloric acid will cause much less severe eye injuries than the same accident with a glass bottle containing 5.0 mol dm^{-3} hydrochloric acid.
- the means that can be taken to reduce the severity of the effect of any accident – for example, the teacher or technician preparing bungs with glass tubes before the lesson, or using eye protection such as safety spectacles during all practical work.
- Make an equipment and materials list. This may need to be in sections;
 - materials and apparatus per student or per group (chemicals and glassware)
 - shared equipment per laboratory (water baths, microscopes, pH meters)
 - any chemicals should include concentrations and quantities needed
 - any equipment should include number required
 - any hazard associated with specific chemicals or equipment should also be noted and cross referenced to the risk assessment. Sources of information about safety may be listed in the syllabus (and are reproduced below).
 - The location of storage areas for equipment and chemicals may be cross referenced to this equipment and materials list.
- 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, by 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,
 - was the time allocation appropriate,
 - were the outcomes as expected,
 - did the students enjoy the work,
 - did the students understand the instructions,
 - was the point of the work clear to the students?

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

Risk assessment

All practical work should be carried out in accordance with the health and safety legislation of the country in which it is done. No activities should be attempted if they conflict with such legislation.

Hands-on practical work can be carried out safely in schools. If it is to be safe, then the hazards need to be identified and any risks from them reduced to insignificant levels by the adoption of suitable control measures. These risk assessments should be done for all the activities involved in running practical science classes including storage of materials, preparatory work by the teacher and by any technical support staff and the practical activities that are carried on in the classroom, whether

demonstrations by the teacher or practical activities for the students. Such risk assessments should be carried out in accordance with the health and safety legislation of the country in which they are done.

Risk assessment involves answering two basic questions:

- 1 **how likely is it that something will go wrong?** For example, pupils using a double sided razor blade to cut up carrots are quite likely to cut themselves.
- 2 **how serious would it be if it did go wrong?** For example the consequences of a spark from an experiment landing in an open bottle of magnesium powder are likely to be serious, including spraying burning magnesium all over the laboratory, burning many pupils and setting the laboratory ceiling on fire (based on a real accident).

With the answers to these questions it is now possible to plan the practical activity to minimise the risk of an accident and to minimise how severe any accident might be. In our examples, this might include cutting up the carrot before giving to young pupils, or providing older pupils with an appropriate sharp knife, it might include bringing in to the laboratory only the amount of magnesium powder required for the activity.

How likely it is that something will go wrong depends on who is doing it and what sort of training and experience they have had. You would obviously not ask 11 year old students to heat concentrated sulphuric acid with sodium bromide, or to transfer *Bacillus subtilis* cultures from one Petri dish to another, because their inexperience and lack of practical skills makes a serious accident all too likely. By the time they reach post-16 they should have acquired the skills and maturity to carry such activities out safely.

Decisions need to be made as to whether an activity should be a teacher demonstration only, or could be done by students of various ages. This means that some experiments should normally only be done as a teacher demonstration or by older students. Perhaps with well-motivated and able students it might be done earlier, but any deviation from the model risk assessment needs discussion and a written justification beforehand.

There are some activities that are intrinsically dangerous, and, if included in the suggested activities, should always be changed to more safe modes of practice, for example, there are **no** circumstances under which mouth pipetting is acceptable – pipette fillers of some sort should **always** be used.

Teachers tend to think of eye protection as the main control measure to prevent injury. In fact, personal protective equipment, such as goggles or safety spectacles, is meant to protect from the unexpected. If you expect a problem, more stringent controls are needed. A range of control measures may be adopted, the following being the most common. Use:

- a less hazardous (substitute) chemical;
- as small a quantity as possible;
- as low a concentration as possible;
- a fume cupboard; and
- safety screens (more than one is usually needed, to protect both teacher and students).

The importance of lower concentrations is not always appreciated, but the following examples, showing the hazard classification of a range of common solutions, should make the point.

ammonia (aqueous)	irritant if $\geq 3 \text{ mol dm}^{-3}$	corrosive if $\geq 6 \text{ mol dm}^{-3}$
sodium hydroxide	irritant if $\geq 0.05 \text{ mol dm}^{-3}$	corrosive if $\geq 0.5 \text{ mol dm}^{-3}$
hydrochloric acid	irritant if $\geq 2 \text{ mol dm}^{-3}$	corrosive if $\geq 6.5 \text{ mol dm}^{-3}$
nitric acid	irritant if $\geq 0.1 \text{ mol dm}^{-3}$	corrosive if $\geq 0.5 \text{ mol dm}^{-3}$
sulphuric acid	irritant if $\geq 0.5 \text{ mol dm}^{-3}$	corrosive if $\geq 1.5 \text{ mol dm}^{-3}$
barium chloride	harmful if $\geq 0.02 \text{ mol dm}^{-3}$	toxic if $\geq 0.2 \text{ mol dm}^{-3}$ (or if solid)

Reference to the above table will show, therefore, that if sodium hydroxide is in common use, it should be more dilute than 0.5 mol dm^{-3} . The use of more concentrated solutions requires measures to be taken to reduce the potential risk.

Material Safety Data Sheets. (MSDS)

Your risk analysis should consider the hazards associated with the materials you propose to use. These risks are best assessed by reference to MSDS's appropriate to the chemical(s) in use. These are generally supplied by the chemical manufacturer and supplied with the chemical. If this is not the case then there are many internet sites that have this information freely available. These sheets also provide useful information on the actions to take following an accident, including first aid measures, and should therefore be considered essential for all practical experiments involving chemicals, as part of the risk assessment process.

Hazard key.

The following key applies.

C = Corrosive substance

F = Flammable substance

H = Harmful or irritating substance

O = Oxidising substance

T = Toxic substance

N = Harmful to environment

B = Biohazard

Eye protection

Clearly students will need to wear eye protection. Undoubtedly, chemical splash goggles give the best protection but students are often reluctant to wear goggles. Safety spectacles give less protection, but may be adequate if nothing which is classed as corrosive or toxic is in use.

Your risk assessment should not restrict itself simply to the materials, procedures and equipment being used, but should have a wider remit, covering the time from when the class enter the room until they leave it.

Practical science can be - and should be - fun. It must also be safe. The two are not incompatible.

Safeguards in the School Laboratory, 10th edition, ASE, 1996

Topics in Safety, 2nd edition, ASE, 1988

Hazcards, CLEAPSS, 1998 (or 1995)

Laboratory Handbook, CLEAPSS, 1997

Safety in Science Education, DfEE, HMSO, 1996

Hazardous Chemicals Manual, SSERC2, 1997.

Appendix 1

A2 Skills and Designing a practical course for A2

A2 skills build on the AS skills developed. It cannot be emphasised enough that students will not become competent in these skills without practical experience. The specific investigations to which references are made can be found in appendix 2.

Extending AS skills for the A2 year

As part of their AS studies students will be expected to develop skills in manipulating and measuring using standard laboratory apparatus. These will form a basis on which more advanced manipulative skills will be developed. During their AS course it is assumed that students will learn how to measure accurately and to manage space and time effectively, so that they are confident in their use of apparatus.

- These practical skills will be extended by more complex investigations and the use more specialised apparatus. For instance an investigation into *The effect of nitrate concentration on biomass* extends over several weeks. There is also an opportunity in this investigation to use a more accurate method of measuring concentration using a bioassay. In the Applications section of the syllabus there will be many unfamiliar techniques and quite complex equipment. Here, it is important that the students gain confidence in the use of the apparatus and understand how it works. A number of the investigations are intended to introduce students to the technique, for example electrophoresis equipment, growing microorganisms and using immobilised enzymes. It is anticipated that teachers will develop these into evaluation or planning exercises. For some biotechnology investigations equipment may be restricted, nevertheless, demonstrations can form the basis for planning and evaluation.
- The analysis and evaluation will also be more extensive. Analysis data will involve calculations and statistical testing. The investigation into the effect of nitrate expects the processing of data and the use of error bars. An investigation into *The effect of penicillin on bacterial growth* makes use of t-test to assess results. The Chi square test can be used to evaluate the results of a breeding experiment.

Teaching students to evaluate

Evaluation refers to a number of skills concerned with the design of an experiment – in effect “How well did the experiment work”. Students should question the way in which a procedure is carried out, comment on the reliability of the results and understand the limitations of a method. Students need to acquire these skills before they can progress to the high order A2 skill of planning. The more practice the better – ideally every investigation could be evaluated using a simple check list until it becomes an automatic response by a student.

- In AS students will have been taught to evaluate procedures and suggest improvements. These skills be utilised in A2 and developed into the higher order skills recognising the cause of anomalous and contradictory results and determining how a procedure can be modified to remove potential sources of error. The skill of evaluation is further developed by learning how to assess results in relation to the stated aim or hypothesis of the investigation.

- Students need to be able to judge the reliability of their results. Many students confuse reliability – consistent repeatable results, with accuracy – measuring with the appropriate equipment. One strategy is to compare class results or to compare actual results to theoretical results. Once the reliability is known students can then relate to the aim of the experiment. To develop these skills students need to be encouraged to question. Initially a check list of questions such as: Do I have enough results? How much variability is there in my results? How many results are anomalous? How accurate was the equipment used? Have all the variables been controlled – if not, what should I do to improve this? How else could I have measured? Do my results support the aim/hypothesis – if not, which part and how can I change the procedure?
- Many of the investigations in appendix 4 have aspects of evaluation. *Producing a model industrial immobilised enzyme column*, *The effect of nitrate concentration on biomass* and *The effect of light intensity on rate of the Hill reaction* address these skills in a variety of ways. Any other procedure can be evaluated.

Teaching students to plan experiments

Planning the experiment requires students to formulate a hypothesis, recognise variables and determine how to test a hypothesis. Students cannot access these skills without familiarity with experimental procedures and experience of using apparatus. Skills that are apparently straightforward, such as choosing suitable apparatus and devising an appropriate procedure, become problematical as students are uncertain what to measure or how to measure. Awareness of safety does not really develop unless students are actively involved in activities that involve a potential risk. It is expected that students will be encouraged to use safety information sources, such as Hazcards.

- Evaluation skills are a starting point for planning. At a preliminary level this may be to modify an existing procedure to generate more reliable results. The investigations, *The effect of nitrate concentration on biomass* and *The effect of light intensity on rate of the Hill reaction* can both be used for recognising uncontrolled variables. The investigation *Urine Analysis* could be used for improving reliability by asking students, working in groups, to suggest methods of measuring more accurately the glucose content of sample 1. Part of this activity could include asking the students to identify the potential risks and how they have been addressed by the procedure. The suggested improvement from each group could then be trialled and assessed by another group. This strategy has an additional benefit of training students in writing clear instructions that can be followed by someone else. To develop this skill further, students could be given the task of producing a plan for an investigation using an existing experimental set for a different purpose. The investigation *Producing a model industrial immobilised enzyme column* could be used for this purpose.
- To design their own experiment, students initially need to be in a familiar context. It is helpful to have a check list to prevent critical features of the plan from being omitted. Devising a generic check list by student participation can help to clarify the principles of planning as required by the syllabus learning outcomes. This could be a list of questions or a work sheet to complete. Initially, teachers may choose to give a hypothesis and ask the students to devise a plan. An investigation using *Immobilised algae* could be used in this way by a hypothesis such as "The greater the concentration of

carbon dioxide, the more oxygen is released” or “*The greater the concentration of carbon dioxide, the more oxygen is released*”.

- Once students have reached the stage of planning their investigations it is essential that they try them out. Often plans do not work as anticipated, so students need to evaluate and refine their plans. It is common for students to make unrealistic choices of apparatus and quantities, but unless they are given the opportunity to try, they remain unconvinced. Students should be encouraged to use the apparatus available, which may limit the syllabus contexts from which planning exercises may be drawn. If resources are limited then many biotechnology contexts are unsuitable, although investigations *The effect of penicillin on bacterial growth* and *Estimating the population growth of yeast* provide contexts from which hypotheses could be devised and tested usually relatively inexpensive equipment. For example, “*Bacteria are killed more effectively by soap than by detergent*” or “*Yeast population increases faster at low pH*”
- The plans produced by students are by their nature different from each other. If the same hypothesis is being tested, then there may be similarities. However, once students devise their own hypotheses then there may well be significant differences. This has implications for both resources and supervision. One strategy mentioned in the section on delivering practical skills is to incorporate planning into a circus of activities, particularly if resources are limited. However, planning and evaluation do not need to be carried out in a laboratory. So these could be carried out in a classroom, planning in a lesson before hand, trialling in a laboratory and evaluating as homework or as a follow up classroom activity. Another issue to consider is the preparation time for student planned activities. As part their plan students should produce an equipment list, with quantities that can be handed in to the person responsible for the preparation. For standard laboratory equipment, students should know where this is stored and be able to get it for themselves, but the person responsible for resources will need to know the overall requirements to ensure that there is sufficient available.

Outline List of Practical Experiments

Syllabus section	Skills/Learning Outcomes	Notes	Sources
L	Practical 11 - Respirometer		
(k),(l), (m)	<ul style="list-style-type: none"> Identify the independent and dependent variables Test a hypothesis Experience relevant methods, analysis, conclusions and evaluation Explain RQ values in terms of substrate use Suggest modifications for use with photosynthesising organisms 	<p>Use small invertebrates. Blow fly larvae, woodlice, cockroaches and germinating seeds. Evaluating a single arm respirometer allows the introduction of more complex respirometers with balanced pressure.</p> <p>Students should be asked to how the apparatus can be modified to test a green plant.</p>	<p>Biology Resource Pack A2</p> <p>Lea, Lowrie and McGuigan</p>
M	Practical 12 - Immobilised Algae – effect of limiting factors on the rate of photosynthesis		
(f), (g)	<ul style="list-style-type: none"> Evaluation *discuss limiting factors in photosynthesis and carry out investigations on the effects of light intensity and wavelength, carbon dioxide and temperature on the rate of photosynthesis; 	<p>Use sodium alginate mixed with algae to produce beads by transferring the alginate/algae mixture drop wise into calcium chloride solution</p> <p>Students should be asked to consider the advantages of immobilising the algae in this way and review other methods of immobilisation (in relation to syllabus section S).</p> <p>Students could be asked to plan to test the effect of either carbon dioxide or temperature</p>	<p>Advanced Biology Study Guide Clegg and Mackean</p>

Syllabus section	Skills/Learning Outcomes	Notes	Sources
N	Practical 13 - Factors that affect the opening and closing of stomata		
(f), (g)	<ul style="list-style-type: none"> • Identify the independent and dependent variables • Formulate a hypothesis and express this in words and graphically • Experience relevant methods and analysis, conclusions and evaluation • Plan an investigation 	<p>Use a number of solutions to bathe whole leaves or leaf discs. Calcium chloride, sodium chloride, potassium chloride, sucrose, glucose can all be used. Concentrations will need to be trialled depending on the leaves used. Measure the size of the stomata using epidermal strips or nail varnish impressions. Find the mean size and present graphically. Test whether any differences are significant. Plan an investigation to determine the effect of abscissic acid.</p>	<p>Advanced Biology Study Guide Clegg and Mackean</p>

Syllabus section	Skills/Learning Outcomes	Notes	Sources
N	Practical 14 - Reflexes		
(e), (f), (g)	<ul style="list-style-type: none"> • Identify the independent and dependent variables • Formulate a hypothesis and express this in words and graphically • Experience relevant methods, analysis, conclusions and evaluation • Describe and explain the reflex arc that occurs during a knee-jerk reflex, swallowing reflex, iris reflex and blinking reflex • Evaluate the procedure, discussing why it is difficult to quantify this investigation 	<p>Using a tendon hammer and working in pairs, students should test each others knee-jerk reflexes by tapping the joints just below the knee, and then the ankle. Students should compare the intensity of the reactions from the knee and ankle.</p> <p>Students can also observe that it is virtually impossible to swallow twice in rapid succession unless liquid is present in the mouth. Students should try to explain the reflex which the liquid induces.</p> <p>Students can observe one another's eyes to note the change in the iris when their partner looks toward a light then try to explain the reflex arc that occurs.</p> <p>Students should try and explain the reflex arc that occurs when a person claps their hands in front of another's face, causing them to blink.</p>	

Syllabus section	Skills/Learning Outcomes	Notes	Sources
N	Practical 15 - Reaction time		
(e),(f), (g)	<ul style="list-style-type: none"> • Identify the independent and dependent variables • Make a hypothesis and express this in words and graphically • Experience relevant methods, analysis, conclusions and evaluation • Describe and explain the reflex arc that occurs during reaction timing • Explain the ability to improve reaction time with practice 	<p>Using a reaction timing ruler and working in pairs, students should test each other's reaction time. This is done by one student holding the ruler between their partner's thumb and forefinger, which should be approx 2 cm apart, their elbow resting on a table to keep the hand from moving up or down. The ruler is then dropped and the student catches it as soon as possible, reading the reaction time off the ruler from the position of their thumb.</p> <p>Students should be asked to record their reaction time and repeat several times, observing any improvement with practice.</p>	<p>Biology 9700</p> <p>University of Cambridge International Examinations</p>

Syllabus section	Skills/Learning Outcomes	Notes	Sources
(c)	<ul style="list-style-type: none"> • Recognise the gross structure of the mammalian kidney • Interpret the microscopic image of the kidney via viewing sections under a light microscope • Experience relevant methods • Produce a biological drawing of kidney histology, as viewed under a light microscope 	<p>Students should dissect a pig's or lamb's kidney along the perimeter of the convex side so it may be opened up and the internal structures observed. Students should be asked to identify the ureter, pelvis, cortex and medulla of the kidney and the glomeruli may be observed using a hand lens.</p> <p>Students should be asked to observe a prepared section of kidney under a light microscope and to identify the glomeruli, renal capsule (Bowman's capsule), the renal tubules, the collecting ducts and the loops of Henle.</p> <p>Students should produce a drawing of their observations.</p>	<p>An Atlas of Histology</p> <p>Freeman and Bracegirdle</p> <p>Bioscope</p>

Syllabus section	Skills/Learning Outcomes	Notes	Sources
N	Practical 16 - Model kidney tubule		
(c)	<ul style="list-style-type: none"> • Identify the independent and dependent variables • Make a hypothesis and express this in words and graphically • Experience relevant methods, analysis, conclusions and evaluation • Describe and explain the function of the kidney tubule 	<p>Students should produce a model of the filtration in a kidney tubule using visking tubing and a syringe. Pressure applied by pushing the syringe simulates hydrostatic pressure. Small molecules will pass through the membrane (to be re-absorbed) whilst others will remain inside the tubing. This is possible by using albumin and glucose and placing the model in a beaker of water. The water can then be tested for both protein and glucose using Biuret and Benedict's reagent respectively.</p>	
N	Practical 17 - Structure and histology of an Islet of Langerhans in the mammalian pancreas		
(m)	<ul style="list-style-type: none"> • Interpret the microscopic image of the pancreas by viewing sections under a light microscope • Experience relevant methods • Produce a biological drawing of pancreas histology, as viewed under a light microscope 	<p>Students should observe a prepared section of a pancreas under the microscope. Students should be asked to identify the two different types of secretory tissue present. Students should draw a high power drawing showing the arrangement of the two different types of secretory material. These diagrams should be annotated with the main features that distinguish exocrine gland (enzyme) from the endocrine (islet of Langerhans) tissue.</p>	<p>An Atlas of Histology</p> <p>Freeman and Bracegirdle</p> <p>Bioscope</p>

Syllabus section	Skills/Learning Outcomes	Notes	Sources
O	Practical 18 - Meiosis		
(a)	<ul style="list-style-type: none"> Use of microscope at medium power to observe the nuclei of cells undergoing meiosis Use appropriate apparatus and techniques 	Use anthers from a flowering plant of <i>Tradescantia virginiana</i> or a dormant bulb of <i>Hyacinthus</i> . Stain anthers with acetic orcein. If pollen grains are visible then meiosis has already occurred. If large nuclei are present the plant is too young.	<p>Advanced Biology Study Guide by Clegg and Mackean</p> <p>Philip Harris-meiosis sets</p> <p>Bioscope <i>Lilium</i> anther</p>
O	Practical 19 - Chi-Squared Test		
(f)	<ul style="list-style-type: none"> Application of Chi-squared test Use of Chi-squared test to evaluate results of breeding experiments Use of Chi-squared test to evaluate Mendelian ratios Data handling 	Calculate Chi-squared value of a set of data obtained from a genetic experiment. Test the significance of differences between observed and expected results. The Chi-squared test can also be used to evaluate the results of ecological sampling in the context of Q (d).	<p>Advanced Biology Study Guide by Clegg and Mackean</p> <p>A2 Biology AQA B by Lea, Lowrie and McGuigan</p>
O	Practical 20 - Mutation in a Fungus		
(b) (g) (f)	<ul style="list-style-type: none"> Use the fungus <i>Sordaria fimicola</i> to obtain Mendelian ratios. Use of microscope to visualise and score Asci Data analysis to determine crossing over frequencies 	It is possible to culture <i>Sordaria fimicola</i> . Using standard corn agar. Use the strain with black ascospores crossed with the strain with off-white ascospores to obtain Mendelian ratios.	Practical Genetics Open University Press

Syllabus section	Skills/Learning Outcomes	Notes	Sources
P	Practical 21 - Variation – Using statistics		
(b)	<ul style="list-style-type: none"> • Application of statistics in Biology to test for the significance of differences between samples. • Use standard deviation to estimate the spread of data • Use t-test to compare two sets of normally distributed data • Data handling 	<p>Calculate mean and standard deviation for a set of grouped data. Calculate the value of t and determine if there is a significant difference.</p> <p>Samples of leaves from the same species growing in different areas, height of seedlings grown in different pH</p>	<p>Advanced Biology Study Guide by Clegg and Mackean</p> <p>Advanced Level Practical Work for Biology Hodder and Stoughton</p>
P	Practical 22 - Simulation of selection and evolution		
(g)	<ul style="list-style-type: none"> • Analysis of results • Express results graphically • Draw conclusions 	<p>A large number of beads (counters/plastic) of two different colours in a beaker. Start at 50% each colour to represent alleles. One colour represents dominant. Pick at random 2 beads and place together to represent genotypes. Repeat until all beads used – group according to phenotype. Decide on selection pressure e.g. 25% of dominant phenotype and remove. Return all others to beaker and repeat several generations. By changing the selection pressure can show results graphically.</p> <p>Can modify to show isolation by splitting beads into 2 populations an applying different selection pressure.</p>	<p>Biology 9700</p> <p>University of Cambridge International Examinations</p> <p>Scheme of work</p>

Syllabus section	Skills/Learning Outcomes	Notes	Sources
P	Practical 23 - Population growth		
(c)	<ul style="list-style-type: none"> • Analyse results • Draw conclusions • Express results graphically • Use a complex technique 	Use yeast or bacterial culture. Measure population growth using haemocytometer. Bacteria measure twice daily, 3-4 days. Yeast daily, 5-6 days. Population growth curve, should show slowing down due to limiting factors.	Advanced Biology Study Guide by Clegg and Mackean
Q	Practical 24 - Comparing diversity in a managed and unmanaged environment		
(a) (g)	<ul style="list-style-type: none"> • Analysis of results • Express results graphically • Statistical analysis • Draw conclusions 	Two areas relatively easily accessible, one managed in some way – lawns, parts, farm land, fished water; the other unmanaged – woodland, conservation sites with access, waste land, unfished water. One could be the Centre grounds the other the side of a road. Use suitable sampling equipment to collect data on the number of different species in an area. Use Lincoln index and Chi square	

Syllabus section	Skills/Learning Outcomes	Notes	Sources
R(g)	Practical 25 - Electrophoresis		
	<ul style="list-style-type: none"> • Identify the independent and dependent variables • Make a hypothesis and express this in words and graphically • Experience relevant methods, analysis, conclusions and evaluation • Describe the processes of electrophoresis as used in DNA fingerprinting and DNA sequencing • Describe and explain an electrophoresis gel after running and staining 	<p>Students should first extract a sample of DNA from fruit or vegetables (see extended practical) and then cut the DNA using restriction enzymes. The cut DNA can then be used in electrophoresis (see extended practical) and stained with an appropriate stain when complete.</p> <p>Students should analyse the results of the electrophoresis and compare to other result or DNA fingerprints to try and identify 'matches'</p> <p>*Can be followed up by discussion on genetic screening and counselling.</p>	<p>NCBE DNA technology kit</p> <p>Bio-Rad DNA fingerprint kits</p> <p>*NCBE</p> <p>DICE work pack</p>
S	Practical 26 - ELISA - Using antibodies to detect disease		
(h)	<ul style="list-style-type: none"> • Describe antigen-antibody interactions • Understand how HIV is detected • Learn how disease agents are transmitted, diagnosed and tracked • Understand how antibodies are produced in the laboratory for use in diagnostic tests • Study enzyme-substrate mechanics. 	<p>The kits come with a selection of investigations and work sheets. These can be used directly or modified to become the basis of planning exercises.</p> <p>The kit gives the flexibility to perform 3 different ELISA-based protocols. Protocols I and II test for the presence of antigen in unknown samples and Protocol III for the presence of antibody. The positive control is either an antigen or an antibody depending on the protocol being followed. Each kit includes a Teacher's Guide, Student Manual and graphic Quick Guide.</p>	<p>Bio-Rad Laboratories Immuno Explorer Kit</p>

Syllabus section	Skills/Learning Outcomes	Notes	Sources
T	Practical 27 - Adaptations in crop plants		
(h)	<ul style="list-style-type: none"> • Recognise the structure and • make accurate drawings of a maize leaf • Understand the difference in organisation of a C4 and C3 leaf • Recognise sorghum and rice • Be able to describe and explain the adaptations of rice and sorghum • Plan an investigation to test the effect of ethanol concentration on the growth of germinated rice. 	<p>Microscope slides of maize leaves to look at distribution of chloroplasts. Revisit dicot leaf from Syllabus section M. Draw up comparisons.</p> <p>Actual or museum specimens of sorghum and rice - observations of general morphology.</p> <p>Germinated rice seedlings – grow in different concentrations of ethanol</p>	<p>Bio-Rad Laboratories Immuno Explorer Kit</p>
U	Practical 28 - Microscopic examination of reproductive organs		
	<ul style="list-style-type: none"> • Identify a section of an ovary and testis • Recognise different stages in the gametogenesis in a testis by appearance and position of cell • Recognise the appearance of immature and mature follicles in an ovary • Recognise the appearance of a corpus luteum in an ovary • Estimate the number of ovulations by counting corpora albicans 	<p>Can be a circus activity if slides are limited. Student work sheet with labelled diagrams and photomicrographs. Students identify and draw the specified structures.</p> <p>Demonstration dissection or museum specimens to show location of reproductive structures. These can also be used to simulate the techniques of ivf.</p> <p>Slides of uterus wall can be used to demonstrate layers.</p>	<p>An Atlas of Histology</p> <p>Freeman and Bracegirdle</p> <p>Human Systems</p> <p>Griffin and Redmore</p>