Investigative Biology (Advanced Higher)

The **Mandatory Course key areas** are from the *Course Assessment Specification*. Activities in the **Suggested learning activities** are not mandatory. This offers examples of suggested activities, from which you could select a range of suitable activities. It is not expected that all will be covered. Centres may also devise their own learning activities. **Exemplification of key areas** is not mandatory. It provides an outline of the level of demand and detail of the key areas.

In the **Suggested learning activities**, there are references to the use of case studies. These should be seen as a suggested approach to teaching and learning and not confused with the use of case study as a method of Course assessment. These case studies should make learning active, challenging and enjoyable and identify for the learner the Course content and skills that will be developed. Case studies should be developed in such a way that learners have the opportunity to select activities, where appropriate, and present the opportunity to pursue further study. Case studies need not necessarily be restricted to one Unit but could include biology drawn from different Units.

Mandatory Course key areas	Suggested learning activities	Exemplification of key areas
1 Scientific principles and process (a) Scientific method Scientific cycle — construction of a testable hypothesis, experimental design, gathering, recording, analysis of data, evaluation of results, conclusions and the formation of new hypotheses where necessary. The null hypothesis.	Case study on the successive evidence-based models of the structure of the plasma membrane to illustrate refinement of scientific knowledge through a framework of experimentation. Discuss importance of publication of negative results in the fields of pharmaceutical or medical research, for example. Consider Karl Popper's concept of falsifiability as the basis for scientific thinking.	Science is the gathering and organisation of testable and reproducible knowledge. In the scientific cycle, hypothesis testing involves the gathering, recording and analysis of data, followed by the evaluation of results and conclusions. New hypotheses may then be formulated and tested. In science, refinement of ideas is the norm, and scientific knowledge can be thought of as the current best explanation which may then be updated after evaluation of further experimental evidence.

	Investigate examples of recent scientific breakthroughs to try to identify examples of unexpected results, conflicting data or creative experimentation. Consider also the impact of mental inertia on the advancement of science.	Failure to find an effect (ie a negative result) is a valid finding, as long as an experiment is well designed. Conflicting data or conclusions can be resolved through careful evaluation or can lead to further, more creative, experimentation. The null hypothesis can be used in the design of experiments to investigate a possible effect. One-off results are treated with caution. Scientific ideas only become accepted once they have been checked independently.
(b) Scientific literature and communication The importance of publication of methods, data, analysis and conclusions in scientific reports so that others are able to repeat an experiment. The importance of peer review and critical evaluation. The use of review articles, which summarise current knowledge and recent findings in a particular field. Critical evaluation of science coverage in the wider media.	Write a method that can be followed by another investigator. Follow the method provided by another investigator. Through (literal) replication, attempt to verify another investigator's results. Present scientific findings in a report suitable for a primary journal. Use a range of scientific sources to summarise several articles in a scientific review. Contrast the dispassionate approach taken in presenting scientific results with the passionate reality of scientific investigation (eg see Frederick Grinnell's *The Everyday Practice of Science*).	Common methods of sharing original scientific findings include seminars, conference talks and posters and publishing in academic journals. Most scientific publications use peer review. Specialists with expertise in the relevant field assess the scientific quality of a submitted manuscript and make recommendations regarding its suitability for publication. Increasing the public understanding of science and the issue of misrepresentation of science in the media.

(c) Scientific ethics Importance of integrity and honesty — unbiased presentation of results, citing and providing references, avoiding plagiarism. In animal studies, the concepts of replacement, reduction and refinement are used to avoid, reduce or minimise the harm to animals. Informed consent, the right to withdraw data and confidentiality in human studies. The justification for scientific research including the assessment of any risks. Legislation, regulation, policy and funding can all influence scientific research.	Discuss excerpts from Ben Goldacre's *Bad Science*. Use an online plagiarism checker to check scientific writing. Using a standard system, make appropriate citations in a piece of scientific writing and construct a reference list that allows another investigator to locate your source material. Discuss the implications of Russell and Burch's 3Rs on school-based animal studies. Discuss the implications of the British Psychological Society's ethical guidelines on school-based investigations on humans. Discuss the impact of legislation, market forces, patents, government funding and charitable funding on scientific research.	While judgements and interpretations of scientific evidence may be disputed, integrity and honesty are of key importance in science. The replication of experiments by others reduces the opportunity for dishonesty or the deliberate misuse of science. The requirement to cite and supply references. In human studies, informed consent, the right to withdraw data and confidentiality are important considerations. The value or quality of science investigations must be justifiable in terms of the benefits of its outcome including the pursuit of scientific knowledge. The risk to and safety of subject species, individuals, investigators and the environment must be taken into account. As a result, many areas of scientific research are highly regulated and licensed by governments. Legislation limits the potential for the misuse of studies and data.
2 Experimentation (a) Pilot study The use of a pilot study to develop and/or practice protocols in order to ensure validity of experimental design, check effectiveness of techniques, find a suitable range of values for the independent	Follow a multi-step protocol, such as protein electrophoresis, mitotic index or cell cycle mutation in yeast, to appreciate need for practice of difficult techniques. Use a pilot study to establish ranges for variables in an investigation such as	Integral to the development of an investigation, a pilot study is used to help plan procedures, assess validity and check techniques. This allows evaluation and modification of experimental design. A pilot study can be used to develop a

variable, identify and control confounding variables, identifying suitable numbers of replicates.	enzyme activity or Daphnia heart rate. Carry out a pilot study for the Biology Investigation.	new protocol or to enable an investigator to become proficient in using an established protocol. The use of a pilot study can ensure an appropriate range of values for the independent variable to avoid results for the dependent variable ending up 'off the scale'. In addition, it allows the investigator to establish the number of repeat measurements required to give a true value for each independent datum point. A pilot study can also be used to check whether results can be produced in a suitable time frame.
(b) Variables Controlling and or monitoring confounding variables, including randomised block design. Discrete and continuous variables give rise to qualitative, quantitative or ranked data.	Consider the operationalisation (ie what measurements are actually being taken) for a set of independent, dependent and confounding variables, for example in the context of an investigation into reproductive investment, courtship or mate choice in Drosophila or stickleback. Examine sources of data derived from qualitative, quantitative and ranked variables and decide how to analyse and present the results appropriately.	Due to the complexities of biological systems, other variables besides the independent variable may affect the dependent variable. These confounding variables must be held constant if possible, or at least monitored so that their effect on the results can be accounted for in the analysis. In cases where confounding variables cannot easily be controlled, blocks of experimental and control groups can be distributed in such a way that the influence of any confounding variable is likely to be the same across the experimental and control groups. Variables can be discrete or continuous and give rise to qualitative, quantitative or

		ranked data. The type of variable being investigated has consequences for any graphical display or statistical tests that may be used.
(c) Experimental design Controls, dependent and independent variables. The use and limitations of simple (one independent variable) and multifactorial (more than one independent variable) experimental designs. Advantages and disadvantages in vivo and in vitro studies. Investigators may wish to use groups that already exist, so there is no truly independent variable. These ‘observational’ studies are good at detecting correlation but, as they do not directly test the model, they are less useful for determining causation.	Consider an area of research and design a true experiment and an observational study. Contrast the strength of any conclusions that could be drawn from these types of study. Design and carry out a simple laboratory true experiment, such as an enzyme experiment, where confounding variables are tightly controlled. Design and carry out a field observational study, such as an environmental transect, where the independent variable is not under direct control and where confounding variables cannot be tightly controlled. Carry out an observational study where the investigator groups the independent variable, such as a study of the effect of gender in a human study.	Experiments involve the manipulation of the independent variable by the investigator. The experimental treatment group is compared to a control. Simple experiments involve a single independent variable. A multifactorial experiment involves a combination of more than one independent variable or combination of treatments. The control of laboratory conditions allows simple experiments to be conducted more easily than in the field. Similarly, experiments conducted in vivo tend to be more complex than those in vitro. However, a drawback of a simple experiment is that its findings may not be applicable to a wider setting.
(d) Controls Control groups are used for comparison with treatment results. The negative control group provides results in the absence of a treatment. A positive control is a treatment	Design an experiment with positive and negative controls, such as a laboratory investigation using an enzyme.	

that is included to check that the system can detect a positive result when it occurs.		
(e) Sampling Where it is impractical to measure every individual, a representative sample of the population is selected. The extent of the natural variation within a population determines the appropriate sample size. More variable populations require a larger sample size. A representative sample should share the same mean and the same degree of variation about the mean as the population as a whole. In random sampling, members of the population have an equal chance of being selected. In systematic sampling, members of a population are selected at regular intervals. In stratified sampling, the population is divided into categories that are then sampled proportionally.	Consider aspects of sampling in investigating heart rate in Daphnia or contraction of muscle due to ATP. Is variation in sample representative of natural variation in Daphnia or muscle tissue? Are the samples of Daphnia or muscle tissue independent? Condense data from non-independent samples (ie same Daphnia; tissue from same muscle). In ecological studies use random numbers to select quadrats for sampling. Establish sample size by determining a travelling mean or the cumulative total of species in quadrats. Use line or belt transects to systematically sample an environment. Use stratified sampling to sample habitats that are not uniform using a standard formula to calculate the number of samples from each area.	
(f) Ensuring reliability Variation in experimental results may be due to the reliability of measurement methods and/or inherent variation in the specimens. The precision and accuracy of repeated measurements. The natural variation in the biological	Determine the precision of a measuring procedure by repeated measurements and the accuracy of a measuring procedure by calibration against a known standard. Use measures of central tendency to	The reliability of measuring instruments or procedures can be determined by repeated measurements or readings of an individual datum point. The variation observed indicates the precision of the measurement instrument or procedure but not necessarily its accuracy.

material being used can be determined by measuring a sample of individuals from the population. The mean of these repeated measurements will give an indication of the true value being measured. Repeating experiments as a whole to check the reliability of results.	measure the extent of natural variation in samples. Check the consistency of results by repeating experiments, pooling results or reference to scientific literature.	Overall results can only be considered reliable if they can be achieved consistently. The experiment should be repeated as a whole to check the reliability of the results.
3 Critical evaluation of biological research (a) Evaluating background information. Scientific reports should contain — an explanatory title, a summary including aims and findings, an introduction explaining the purpose and context of study including the use of several sources, supporting statements, citations, and references. A method section should contain sufficient information to allow another investigator to repeat the work.		Background information should be clear, relevant and unambiguous. A title should provide a succinct explanation of the study. A summary should outline the aims and findings of the study. The introduction should provide any information required to support methods, results and discussion. An introduction should explain why the study has been carried out and place the study in the context of existing understanding. Key points should be summarised and supporting and contradictory information identified. Several sources should be selected to support statements, and citations and references should be in a standard form. Decisions regarding basic selection of study methods and organisms should be covered, as should the aims and hypotheses.

(b) Evaluating experimental design Experimental design should test the intended aim or hypothesis. Treatment effects should be compared to controls and any confounding variables. The effect of selection bias and sample size on representative sampling.		The validity and reliability of the experimental design should be evaluated. An experimental design that does not test the intended aim or hypothesis is invalid. Treatment effects should be compared to controls; the validity of an experiment may be compromised where factors other than the independent variable influence the value of the dependent variable. Selection bias may have prevented a representative sample being selected. Sample size may not be sufficient to decide without bias whether the modification to the independent variable has caused an effect in the dependent variable.
(c) Evaluating data analysis The appropriate use of graphs, mean, median, mode, standard deviation and range in interpreting data. A statistically significant result is one that is unlikely to be due to chance alone. Confidence intervals or error bars are used to indicate the variability of data around a mean. If the treatment average differs from the control average sufficiently for their confidence intervals not to overlap then the data can be said to be different.	Compare variation in data in simple laboratory experiments on protein binding with that from complex ecological observational studies on biomes. Attempt to evaluate the validity of two methods investigating one scientific problem but producing conflicting results. Explore sets of data on energy flow in ecosystems using simple statistical procedures. Use a statistical test to confirm or refute significance of results of epidemiological study into disease.	In results, data should be presented in a clear, logical manner suitable for analysis. Data may be quantitative or qualitative, depending on the variables investigated. Data are explored through the appropriate use of simple statistical procedures such as graphs, mean, median, mode, standard deviation and range. Consideration should be given to the validity of outliers and anomalous results. Statistical tests are used to determine whether the results are likely or unlikely to have occurred by chance.

(d) Evaluating conclusions Conclusions should refer to the aim, the results and the hypothesis. The validity and reliability of the experimental design should be taken into account. Consideration should be given as to whether the results can be attributed to correlation or causation. Conclusions should also refer to existing knowledge and the results of other investigations.	Compare and evaluate a variety of discussions written about the same set of data on apoptosis in a cell culture. Discuss correlation and causation in the context of genome-wide association studies (GWAs).	Meaningful scientific discussion would include consideration of findings in the context of existing knowledge and the results of other investigations. Scientific writing should reveal an awareness of the contribution of scientific research to increasing scientific knowledge and to the social, economic and industrial life of the community.