S317 Biological science: from genes to species

Are you ready for S317?

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1.1

1 Introduction

S317 *Biological science: from genes to species* explores a range of advanced topics in biological science from evolution to cell and molecular biology. It deals with fundamental aspects of modern Biology through the study of speciation and evolutionary processes, the origin of variation and genome evolution, the control of gene expression and cell behaviour, the life and death of cells, development and ageing. Details about the specific biological topics covered in the module can be found in the module description.

Note that S317 is a **fully onscreen module**; it has no printed material. This may be a new way of working, even for experienced OU students. You should take particular note of the computing requirements for this module:

http://www.open.ac.uk/courses/modules/s317#study-materials

Building on S294 *Cell biology* and S295 *The biology of survival*, this module will extend your understanding of these diverse topics in Biology, as well as further developing your key research skills through a mix of onscreen practical and scientific literacy activities and 'at home' field-based investigations.

If you have not studied S294 and / or S295, you may find it useful to take a look at some of the content of these modules, available online through OpenLearn:

S294: http://www.open.edu/openlearn/science-maths-technology/science/tour-the-cell/content-section-0

S295: http://www.open.edu/openlearn/science-maths-technology/science/migration/content-section-0

If you are intending to study S317, you will want to make sure that you have the necessary background knowledge and skills to be able to enjoy the module fully and to give yourself the best possible chance of completing it successfully. This Are you ready for? (AYRF) quiz is intended to help you find out whether or not you are ready for S317, or if you need to brush up on your knowledge and skills in advance.

Please read through this information carefully, and work through the self-assessment questions (SAQs). Answers are provided to the questions at the end of this document. You should allow yourself about two hours to work through the questions.

This exercise will be useful for all prospective students of S317, even for those of you who have already studied other OU science modules and have completed the suggested prior study (see Section 2); working through this information will serve as a reminder of some of the relevant facts, skills and concepts that you should be bringing with you from earlier study.

Please note that **you shouldn't expect to be able to answer all the questions correctly** now, but attempting them should allow you to judge:

(a) the areas where some reading beforehand would be useful

(b) whether you will be able to cope with the demands of the module.

As a guide, if you manage to get at least half the questions right, you should be able to cope with a bit of directed study in areas in which you struggled to answer questions correctly. Where questions require some extended writing, you should not be surprised if your answer does not correspond to the model answers provided as these may contain some very specific details. Also, some answers offer some further explanation or relevant discussion which you would not be

expected to provide. The important thing to try to gauge is whether you understand the relevant principles and concepts.

If, after working through these questions, you are still unsure about whether or not S317 is the right module for you, we advise you to seek further help and advice from Student Support. The S317 module team look forward to welcoming you as an S317 student.

2 Suggested prior study

This is a Level 3 module and you need to have a good knowledge of biology, obtained through Level 1 and 2 study with the OU, or with another higher education institution. Students who are appropriately prepared have the best chance of completing their studies successfully and get most enjoyment and satisfaction out of the module.

You are expected to be familiar with the biology and chemistry taught in *Exploring science* (S104) or similar, and biology from *Cell biology* (S294) and *The biology of survival* (S295). You should also have knowledge of basic maths and principles of experimental design as provided by *Investigative and mathematical skills in science* (S141), and *The biology of survival* (S295).

If you are coming to S317 without having studied one or more of the OU modules recommended, then it is essential that you establish whether or not your background and experience give you a sound basis on which to tackle the work.

3 Key biological concepts for S317

Biology is a very broad subject area. S317 does not attempt to teach across all of Biology, but instead trades comprehensive coverage for depth of study in selected areas. None-the-less, the topics that have been selected do require an understanding of a broad range of key aspects of Biology from whole organism biology, ecology and evolution to cell and molecular biology.

The self-assessment questions in this document address key biological concepts, an understanding of which is required for successful study of S317.

3.1 Natural selection, evolution and classification

Evolution is central to biology and **natural selection** is the mechanism that produces **adaptation**. Through the process of natural selection, populations of plants and animals evolve; in other words their morphology and their genetic make-up changes over time in response to their changing environment, resulting in the appearance of new species.

However, for selection to occur there must be **variation** within a population, because if every individual is identical, there is nothing for selection to act upon. So, for example, there is variation in beak size in finches and those individuals with beaks well-suited to a particular size of seed do better than others in the population and are therefore favoured by natural selection.

SAQ 1

In a single sentence, write down what you understand by the term ‘adaptation’.

SAQ 2

Write down a few sentences that illustrate your understanding of natural selection.

SAQ 3

What three criteria must be met within a population of interacting individuals in order for natural selection to occur?

SAQ 4

(a) Arrange the following groups in order from the largest (most inclusive) to the smallest (most specific).

family

phylum

order

class

genus

(b) A scientific name contains information about its:

A: class and family

B: phylum and order

C: genus and species

D: family and species.

SAQ 5

Two extant species (X and Y) are placed in the same genus and a third extant species (Z) is placed in a different genus.

(a) Assuming this classification reflects evolutionary relatedness, which of the following is the most accurate phylogenetic tree?

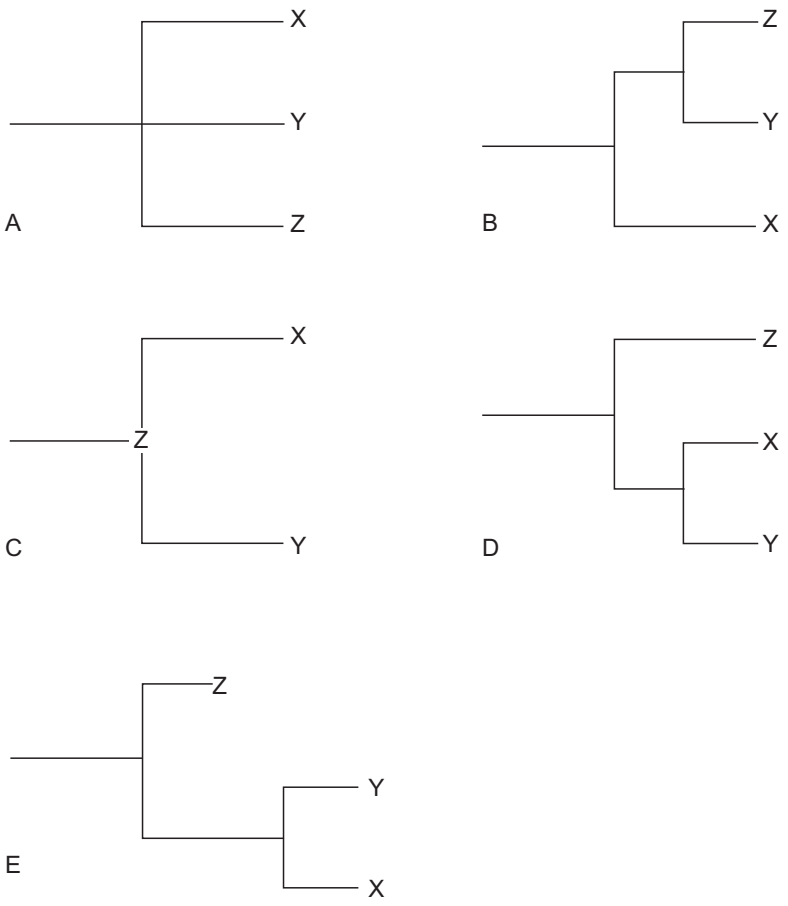

Figure 1 Multiple choice answers for SAQ 5.

(a) Which of the following statements should be true?

A. Species X and Y are not related to species Z.

B. Species X and Y share a greater number of homologies with each other than either does with species Z.

C. Species X and Y share a common ancestor that is still extant (in other words, not yet extinct).

D. Species X and Y are the result of artificial selection from an ancestral species Z.

E. Species X, Y, and Z share a common ancestor, but nothing more can be claimed than this.

3.2 Genes, genomes and inheritance

The basis for evolutionary change is the operation of natural selection upon heritable variation in the genes of organisms. G**enes** are sections of the DNA **genome** that encode gene products, usually proteins, which form the cell structure and carry out cellular processes. In other words, genes determine the characteristics of the organism.

Genetic variation between individuals is brought about from one generation to the next as a result of recombination, the genetic 'shuffling' that takes place as the result of sexual reproduction, and **mutation**, spontaneous changes in the composition of the DNA.

The sequence of the four nucleotide bases (commonly referred to as A, G, C and T) in DNA provides the **genetic code**, which specifies the sequence of the amino acids within the encoded proteins.

In order to multiply, cells must grow and make a copy of their genome in a process known as **DNA replication**. They then undergo cell division to produce two daughter cells each containing one copy of the genome. Prokaryotes divide by the process of binary fission after replicating their DNA. The process in eukaryotes is more complex because the DNA is packaged into a number of individual **chromosomes** which must be replicated and divided equally between the daughter cells in the process of **mitosis** (or **meiosis** in germline cells).

You are expected to be able to understand and use the terms above.
SAQ 6

For each of the definitions provided below, indicate the appropriate matching term.

Definitions:

- The visible characteristics of an individual organism or a group of organisms.
- The genetic makeup of a particular organism or a group of organisms. The genotype can refer to one or more loci.
- The site on a chromosome that is occupied by a gene; sometimes refers to the gene that occupies a site.
- A particular form of a gene, usually distinguished from others at the same locus by its effect on the phenotype.
- The sum of all the alleles in a population. A single individual has only some of the alleles that are present in the population. A gene pool contains different alleles that may produce different phenotypes, and thereby lead to genetic variation.
- Having identical alleles at a particular gene locus.
- Having different alleles at a particular gene locus.

Terms: homozygous; genotype; allele; phenotype; locus; gene pool; heterozygous.

SAQ 7

Write a one-sentence definition of sexual reproduction.

SAQ 8

What events that occur during meiosis contribute to genetic diversity?

SAQ 9

The completion of meiotic division leads to the formation of:

(a) two haploid daughter cells

(b) two diploid daughter cells

(c) four haploid daughter cells

(d) four diploid daughter cells

(e) none of the options given.

SAQ 10

A commonly grown decorative plant has varieties with yellow or white petals and with large or small petals. Yellow (denoted by the symbol *Y*) is dominant to white (*y*), and large (*L*) is dominant to small (*l*).

(a) What genotype and phenotype would the progeny of a cross between pure-breeding plants with yellow, small petals and pure-breeding plants with white, large petals have?

(b) The plants derived from the cross in part (a) were crossed to each other. Use a Punnett square to determine the genotypes and phenotypes of the progeny of this cross. How many different genotypes and phenotypes are there in the progeny?

(c) Plants with yellow, large petals resulting from the cross described in (a) were crossed with plants with white, small petals, yielding four classes of progeny: 228 plants had yellow, large petals, 535 had yellow, small petals, 533 had white, large petals and 232 had white, small petals.

Are the two loci linked or unlinked?

SAQ 11

(a) What are the major differences between prokaryotic and eukaryotic genomes?

(b) Why is the size of the genomes of different complex eukaryotes quite variable?

(c) What are the different types of non-coding DNA found in the human genome?

3.3 Cell and molecular biology

At the broadest level, organisms can be divided in to two groups on the basis of their cell type: organisms with **prokaryotic** cells include the mainly single-celled Bacteria and Archaea while those with **eukaryotic** cells include protists, plants, animals and fungi, and are mostly multicellular. While all cells share certain properties, for example they are all bounded by a **membrane**, there are fundamental structural differences between prokaryotic and eukaryotic cells, and between the features of plant, fungal and animal cells. You also should be familiar with the structure, composition and function in cells of a range of biological **macromolecules** including: **polysaccharides**, **proteins**, **lipids** and **nucleic acids**.

As well as having an understanding of cell structure and composition, you should have some knowledge of basic cellular processes such as the cell cycle, cell division (meiosis and mitosis), cellular respiration, cell transport processes, cell differentiation and fundamental principles of cell signalling.

SAQ 12

You have been provided with a light microscope and a microscope slide on which cells have been smeared. What features would you identify or measure to determine whether the cells are eukaryotic or prokaryotic?

SAQ 13

Match the processes below to their locations within eukaryotic cells.

initiation of protein glycosylation / ribosome assembly / transcription / translation / production of phospholipids

nucleus	
cytosol	
rough endoplasmic reticulum	
nucleolus	
smooth endoplasmic reticulum	

SAQ 14

Figure 2 is a schematic diagram of the secretory pathway in an animal cell.

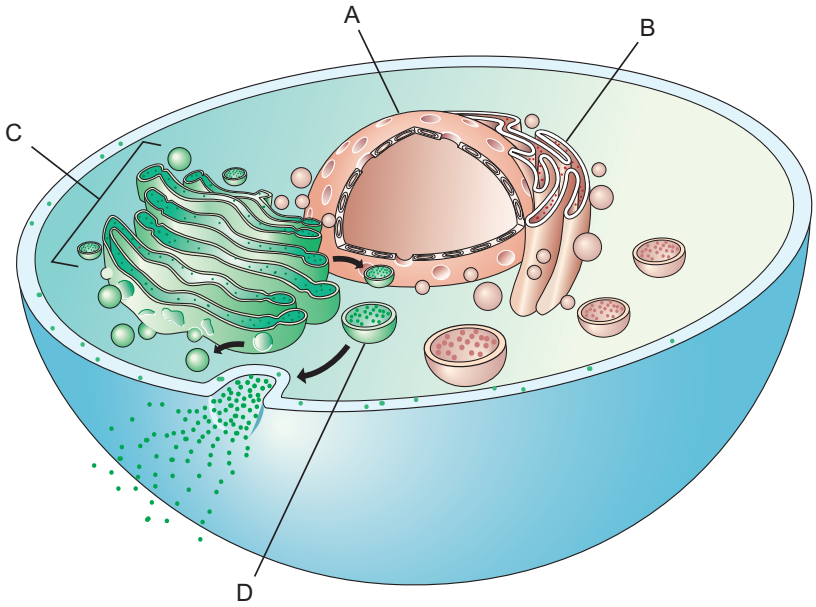

Figure 2 Schematic diagram of the secretory pathway in an animal cell.

(a) Identify the structures labelled A, B, C and D.

(b) Name two processes that take place at B.

SAQ 15

(a) What are the three types of protein filament that make up the cytoskeleton?

(b) What are their component proteins what are their main functions?

SAQ 16

Match the proteins below to their functions during DNA replication.

Proteins: ligase / helicase / DNA polymerase / primase

Functions:

- Adding nucleotides to a chain of nucleotides.
- Separating strands of the double helix.
- Joining together DNA.

Synthesising a short strand of RNA to initiate DNA synthesis.

SAQ 17

(a) Why can the DNA template only be copied in its 3′ to 5′ direction?

(b) During DNA replication, what is the difference between the leading and the lagging strand?

(c) What structures resolve the problem of potential erosion of coding regions by the progressive shortening of the ends of the chromosomes?

SAQ 18

Briefly describe the roles of the following types of RNA during gene expression.

(a) Messenger RNA (mRNA)

(b) Transfer RNA (tRNA)

(c) Ribosomal RNA (rRNA)

SAQ 19

Outline five differences between prokaryotic and eukaryotic gene transcription.

SAQ 20

Which of the following statements about the cell cycle are **false**?

(a) In all cells, mitosis occurs as soon as DNA replication is complete.

(b) Growth factors can stimulate quiescent cells to reenter the cell cycle.

(c) The DNA content of cells that are in G1 is double that of cells in G2.

(d) Cyclin dependent kinases activate the molecules needed for progression through the cell cycle.

(e) Once past the checkpoint in G1 known as ‘start’, a cell is committed to replicate its DNA.

(f) Cyclin is inactivated by the proteasome, after tagging by ubiquitin.

SAQ 21

Of the following statements relating to protein folding and tertiary and quaternary structure, which are **true**?

(a) Disulfide bonds stabilise folded subunits (i.e. tertiary structure) but do not play a role in quaternary structure.

(b) A polypeptide will fold such that it adopts the most stable conformation.

(c) Cytosolic polypeptides fold such that their hydrophobic residues are exposed on their surface.

(d) Histones are proteins that can bind to other misfolded proteins, which are then enabled to refold correctly.

(e) In eukaryotes, misfolded or damaged proteins can be degraded to their constituent amino acids by complexes of proteolytic enzymes (proteases) known as proteasomes.

(f) Some proteins are synthesised as inactive precursors which are activated by hydrolysis of specific peptide bonds by proteases, and can involve removal of a length of polypeptide chain.

SAQ 22

Which of the following statements about enzymes is/are **true**?

(a) Enzymes increase the energy required for the reaction to proceed.

(b) In general, enzymes can operate across a wide temperature range.

(c) Enzymes are chemically altered by the reactions they catalyse.

(d) Extremes of temperature and pH may inactivate an enzyme by altering its conformation.

(e) Although enzymes can speed up the rate at which reactions occur, whether or not a reaction occurs at all depends on whether it is energetically favourable.

SAQ 23

Describe the key structural features of biological membranes as outlined in the fluid-mosaic model.

SAQ 24

Describe the relationships of the structurally different types of membrane proteins to the lipid bilayer and, where appropriate, to each other.

SAQ 25

Which of the following substances are able to cross the cell membrane without the assistance of a specific transport protein?

(a) the amino acid serine

(b) the sugar galactose

(c) the steroid hormone cortisol

(d) nitric oxide (NO) gas.

SAQ 26

Compare and contrast carriers (transporters) and channels.

SAQ 27

(a) How does cell–cell contact-dependent signalling differ from cell–cell signalling via secreted molecules?

(b) What distinguishes autocrine signalling from paracrine signalling?

SAQ 28

(a) What are the three main types of cell surface receptors?

(b) Nitric oxide does not require a cell surface receptor to activate its target protein. Briefly explain why this is the case.

SAQ 29

An overview of glucose oxidation by aerobic respiration is shown in the Figure 3 below.

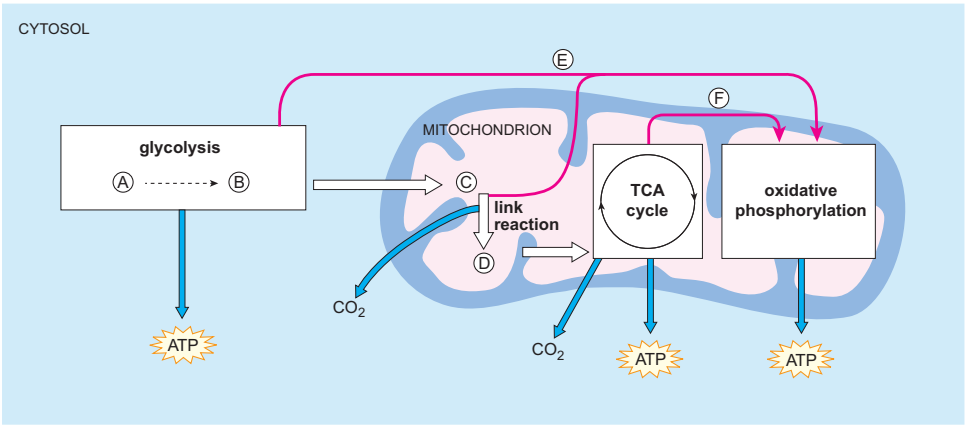

Figure 3 Overview of glucose oxidation by aerobic respiration.

Name the intermediates that are represented by each of the letters A to F.

SAQ 30

(a) What is the name of the initial stage of carbohydrate respiration that occurs in the cytosol?

(b) Name the cell organelle in which the complete oxidation of carbohydrate, the TCA cycle, primarily occurs.

(c) What is the function of adenosine triphosphate (ATP)?

4 Experimental techniques for S317

The variety of techniques used in biological investigations reflects the diversity of this subject and whilst you are not expected to be familiar with very many techniques, there are some which it is assumed you will have come across. You ought to understand the general principles of these techniques and their application:

- Western blotting or immunoblotting
- Electrophoresis (agarose and SDS polyacrylamide electrophoresis)
- Northern blotting
- Polymerase chain reaction (PCR)
- In situ hybridisation (ISH)
- Immunocytochemistry or immunohistochemistry.

SAQ 31

Why do plasmids used for gene cloning carry selectable markers?

SAQ 32

The pancreas is a gland that is specialised to secrete peptide hormones (e.g. insulin), and also digestive enzymes (e.g. trypsin).

(a) What technique would you use to determine whether these two different secretory molecules are stored in the same or different cells of this organ?

(b) What main reagents would be needed to perform this analysis?

SAQ 33

A polymerase chain reaction (PCR) consists of multiple cycles of a three-step reaction, and results in the exponential amplification of a section of DNA. The three steps of each cycle are performed at different temperatures: Step 1 at 94 °C, Step 2 at 55 °C and Step 3 at 72 °C. Briefly explain what the three steps are, and why they are performed at these temperatures.

5 Key skills for S317

There are a number of key skills that you ought to have acquired before studying S317.

If you have trouble answering the questions in this section, you may find the following resources helpful:

The Open University modules Y162 *Starting with maths* and S154 *Science starts here*.

Northedge, A. et al. (1997) *The Sciences Good Study Guide*, Open University Press. ISBN 0 7492 3411 3. Available from Open University Worldwide http://www.ouworldwide.com.

There are various websites offering maths resources, e.g. BBC Learning online Maths learning resources (http://www.bbc.co.uk/learning/subjects/maths.shtml).

5.1 Mathematical skills

You should be able to perform simple calculations, work out percentages and proportions and convert between these. You should be able to use scientific units and scientific notation (powers of ten).

SAQ 34

Put the following measurements into ascending order of magnitude.

10 nm, 1 mm, 0.1 μm, 0.0001 m

SAQ 35

Express the following measurements in the units indicated using scientific notation:

(a) 0.35 nmol l^{-1} as mol l^{-1}

(b) 18 mmol min^{-1} as mol s^{-1}

SAQ 36

This question is about probability. If you have trouble with this question, we recommend that you consider studying the relevant section of the short course S151 Maths for Science prior to tackling S317.

A bag contains equal numbers of blue, green, red and yellow marbles. Marbles are drawn out one at a time, then each is immediately replaced in the bag. What is the probability of drawing the sequence yellow, red, red, yellow?

SAQ 37

This question is about concentrations and molarity.

Concentration is the amount of substance present per unit volume of solution, i.e.

Concentration = amount of substance concentration / volume of solution

Concentration may be expressed as mass per unit volume (e.g. g l^{-1}, mass concentration) or moles per unit volume (e.g. mol l^{-1}, molar concentration).

How many grams of sodium chloride, NaCl, are dissolved in 10 cm^3 of a 0.5 molar solution? (The relative molecular mass of NaCl is 58.44.)

5.2 Statistics

One critical feature of an experimental hypothesis is that it should be testable, preferably using a relevant statistical test.

S295 Investigative Biology Section 6.1 has an overview of how to select the appropriate test.

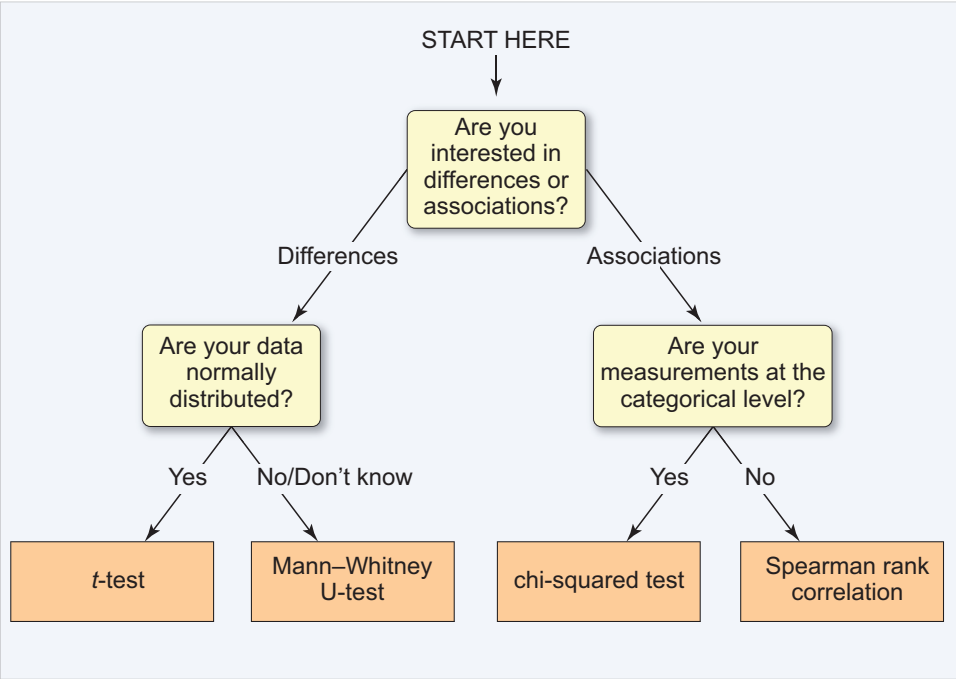

Figure 4 A decision tree to help you determine which statistical test is appropriate (from S295 Investigative Biology Section 6.1).

The following questions ask you to decide on the suitability of a test for particular datasets.

SAQ 38

The *t*-test is the most appropriate test to use when you are looking at:

A: Differences between the means of datasets that are normally distributed.

B: Associations between datasets.

C: Data that is at the categorical level.

SAQ 39

The Chi squared test is the most appropriate test to use when you are looking at:

A: Assessing the significance of the difference between two datasets.

B: Assessing the correlation between two sets of data.

C: Associations between datasets that are at the frequency or categorical level.

5.3 Data interpretation

The broad scope of biology as a subject area and the wide variety of experimental approaches and techniques that are applied in biological investigations means that there are many different types of data generated by such studies.

It is expected that you will be able to interpret graphical representations of data and data tables to extract key information, identify trends in data and draw conclusions based on information provided.

SAQ 40

The allocation of resources to different parts of the plant is under hormonal control enabling them to respond to environmental factors such as water availability (Figure 5).

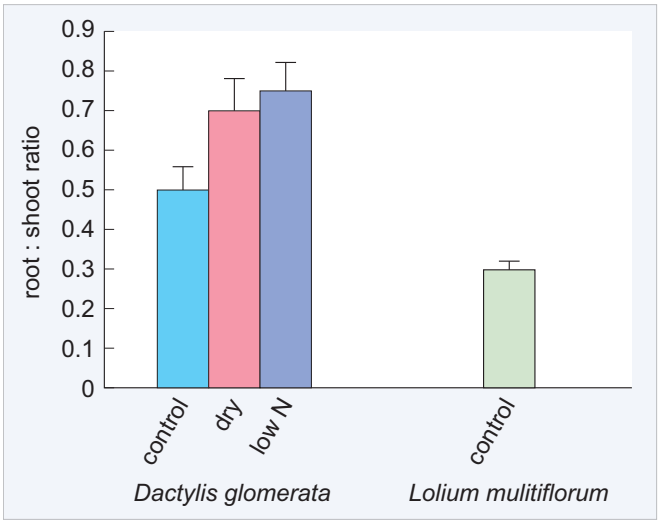

Figure 5 Typical root : shoot ratios for *Dactylis glomerata* growing in well-watered soil, dry soil and soil with a limited availability of nitrogen. An equivalent value for *Lolium multiflorum* grown in well-watered soil is shown for comparison. Error bars indicate the standard error of the mean.

(a) Is the difference in the ratio between plants grown in dry soil and low-N soil likely to be significant?

(b) Suggest why the ratio is greatest when soil resources are limiting.

(c) Comment on the ratio given for *L. multiflorum* relative to *D. glomerata.*

5.4 Scientific Literacy

It is assumed that you will be familiar with the different types of scientific literature and the basic structure of research papers from your prior studies.

SAQ 41

What is ‘primary literature’?

SAQ 42

By the time research papers have been published, most will have actually undergone a specific form of critical review called ‘peer review’. What do you understand to be the role of a peer reviewer?

5.5 Other skills

It is expected that you will have achieved some degree of competence at the other skills listed below.

Basic study skills

You need to have:

- an ability to organise time for study and to pace it
- an ability to analyse tasks and plan how to tackle them
- a willingness to seek help or information when appropriate, and to learn from feedback provided.

Writing skills

You need to be able to present information in a range of formats, e.g. reports, short answers to questions based on information and data abstracted from module materials and scientific texts, in each case keeping to the main points, elaborating where necessary and including figures or making references where appropriate, and ensuring that arguments, ideas and information are presented in a logical sequence.

Cognitive skills

Information processing, including ability to: recognise trends and patterns in data; use evidence to support or refute theories and arguments; assess the adequacy/limitations of explanations; apply knowledge in new contexts, including an ability to recognise associations/relationships, make predictions, extrapolate and interpolate from data.

Basic ICT skills

You have basic skills in: Word processing; Excel; interacting on forums; and using websites. Guidance is provided in S295 on searching the web and using Excel to enter and interpret data, but you need to have at least a basic understanding. Guidance on ICT is available from the OU Computing Guide (http://learn1.open.ac.uk).

6 Further reading for S317

There are many excellent text books available that would be useful for anyone studying S317. You do not need to read any of these books in order to study S317, but the module team suggest the following as useful and relevant texts:

Evolution – An Introduction by Stearns and Hoekstra (Oxford University Press).

Essential Cell Biology by Alberts and Bray (Garland Science).

Molecular Biology of the Cell by Alberts and Johnson (Garland Science).

7 Answers to Self-Assessment Questions

Answer to SAQ 1

An adaptation is a morphological, physiological, biochemical, developmental, or behavioural trait that gives an organism a greater ability to survive and reproduce in a particular environment.

Answer to SAQ 2

Natural selection refers to the differential survival and/or reproduction of organisms due to their physical attributes or phenotype. The concept of selection is central to the theory of evolution by means of natural selection, formulated by Charles Darwin, which forms the cornerstone of many explanations of animal behaviour.

Answer to SAQ 3

The three criteria are:

- there must be phenotypic variation
- phenotypic variation must be genetically determined (so that it can be inherited)
- phenotypic variation among individuals produces variation in some component of fitness, such as survival or mating success, and is ultimately expressed as differential reproductive success.

Answer to SAQ 4

(a) Phylum > class > order > family >genus

(b) C, Genus and species.

Answer to SAQ 5

(a) D

(b) B should be true.

Answer to SAQ 6

Phenotype: The visible characteristics of an individual organism or a group of organisms.

Genotype: The genetic makeup of a particular organism or a group of organisms. The genotype can refer to one or more loci.

Locus: The site on a chromosome that is occupied by a gene; sometimes refers to the gene that occupies a site.

Allele: A particular form of a gene, usually distinguished from others at the same locus by its effect on the phenotype.

Gene pool: The sum of all the alleles in a population. A single individual has only some of the alleles that are present in the population. A gene pool contains different alleles that may produce different phenotypes, and thereby lead to genetic variation.

Homozygous: Having identical alleles at a particular gene locus.

Heterozygous: Having different alleles at a particular gene locus.

Answer to SAQ 7

The production of offspring whose genetic constitution is a mixture of that of two gametes produced by meiosis, which are usually genetically different.

Answer to SAQ 8

Crossing over (recombination) between homologous chromosomes and independent assortment of chromosomes during meiosis results in a huge number of possible gene allele combinations in the gametes.

Answer to SAQ 9

The correct answer is (c). The completion of meiotic division leads to the formation of four haploid daughter cells.

Answer to SAQ 10

(a) The progeny plants would all have yellow, large flowers and the genotype *Yl/yL.*

The pure-breeding parental genotypes must be *Yl/Yl* (yellow, small) yielding only *Yl* gametes, and *yLyL* (white, large), yielding only *yL* gametes. All the progeny will therefore have the genotype *YlyL.* [Note, at this stage we are unable to deduce whether the two genes are linked or unlinked.]

(b) There are nine different genotypes but only four phenotypes:

	YL	***yl***	***Yl***	***yL***
YL	*YL/YL* yellow, large	*yl/YL* yellow, large	*Yl/YL* yellow, large	*yL/YL* yellow, large
yl	*YL/yl* yellow, large	*yl/yl* white, small	*Yl/yl* yellow, small	*yL/yl* white, large
Yl	*YL/Yl* yellow, large	*yl/Yl* yellow, small	*Yl/Yl* yellow, small	*yL/Yl* yellow, large
yL	*YL/yL* yellow, large	*yl/yL* white, large	*Yl/yL* yellow, large	*yL/yL* white, large

(c) The two loci are linked, i.e. they are on the same chromosome. If the loci were on separate chromosomes, you would expect a cross between *Yl/yL* plants and *yl/yl* plants to yield four different phenotypes that would be present at equal frequencies, as shown in the Punnett square below. The fact that they are not present at equal frequencies suggests that the two loci are carried on a single chromosome, and that recombination between homologous chromosomes during meiosis has resulted in unequal frequencies of the four gamete genotypes produced by the parents.

	yl	**Expected frequency of phenotypes if were unlinked**	**Actual numbers of progeny**
YL	*YL/yl* yellow, large	25%	228
yl	*yl/yl* white, small	25%	232
Yl	*Yl/yl* yellow, small	25%	535
yL	*yL/yl* white, large	25%	533

Answer to SAQ 11

(a) Prokaryotes usually have a single chromosome, which is a circular strand of DNA. Some prokaryotes also have small independent circular DNA molecules known as plasmids. Eukaryotes have a nuclear genome, which contains the great majority of its genes, and consists of linear DNA packaged into structures called chromosomes. Eukaryotic chloroplasts and mitochondria also contain small circular genomes that resemble those of prokaryotes, but encode relatively few proteins (many of the proteins in these organelles are encoded by the nuclear genome).

(b) Because the genomes of different eukaryotic organisms contain not only different amounts of coding regions, but also very different amounts of the various types of non-coding DNA.

(c) Non-coding DNA includes: introns, gene regulatory sequences, repetitive DNA (including transposable elements and short repeats), and also unique (i.e. non-repetitive) non-coding sequences. Together these constitute about 99% of the human genome.

Answer to SAQ 12

(i) Cell size: most prokaryotic cells are much smaller than eukaryotic cells, measuring 1–5 μm in diameter, compared with a eukaryotic cell diameter of 10–100 μm. The subcellular features of prokaryotic cells are therefore difficult to discern by light microscopy (LM).

(ii) Presence of nuclei: the nuclei of the eukaryotic cells are visible by LM.

Answer to SAQ 13

nucleus	transcription
cytosol	translation
rough endoplasmic reticulum	initiation of protein glycosylation
nucleolus	ribosome assembly
smooth endoplasmic reticulum	production of phospholipids

Answer to SAQ 14

(a)

A = nucleus

B = endoplasmic reticulum

C = Golgi apparatus

D = secretory vesicle

(b) Processes that take place at B, the endoplasmic reticulum, include:

- synthesis of proteins destined for export from the cell, or inclusion in some cellular membranes
- processing of proteins, for example glycosylation
- cotranslational protein targeting/protein sorting (also cleavage of signal sequences)
- packaging and movement of proteins that are to be processed in the Golgi in transport vesicles.

Answer to SAQ 15

(a) Type of filament: microfilaments; intermediate filaments; microtubules.

(b)

Type of filament	Component proteins	Main functions
microfilaments	actin	• cell motility, for example in the leading edge of moving cells • cell contacts, for example junctions between adjacent cells or between cells and the cell matrix
intermediate filaments	various intermediate filament proteins, for example keratins in mammalian skin cells	• provide mechanical strength
microtubules	tubulin	• maintenance of cell shape • intracellular movement of, for example proteins, chromosomes or organelles

Answer to SAQ 16

Adding nucleotides to a chain of nucleotides: DNA polymerase

Separating strands of the double helix: helicase

Joining together DNA: Ligase

Synthesising a short strand of RNA to initiate DNA synthesis: primase

Answer to SAQ 17

(a) Nucleotides are asymmetrical molecules, so the two strands of DNA are antiparallel, one running 5′ to 3′ and the other 3′ to 5′. DNA polymerase uses one DNA strand as a template to synthesise a new complementary DNA strand. Since the polymerase can only add a new nucleotide by its 5′ end to the 3′ end of the preceding nucleotide in the chain, the new DNA molecule can only be synthesised in a 5′ to a 3′ direction (reading the template DNA strand in a 3′ to 5′ direction).

(b) DNA polymerase can only add nucleotides to the 3′–OH of an existing nucleotide chain. Short RNA primers are synthesised on the template strand to provide the free 3′ end. While the leading strand can be copied continuously as the polymerase moves along one of the template DNA strands in a 3′ to 5′ direction (synthesising the new stand 5′ to 3′), the lagging strand in contrast must be copied discontinuously in short sections (Okazaki fragments) in the opposite direction; an RNA primer strand is synthesised providing a free 3′ end for synthesis of a short section of new strand.

(c) This problem of shortening of the ends is overcome by the addition of short DNA repeats, called telomeres, to the ends of chromosomes.

Answer to SAQ 18

(a) Messenger RNA (mRNA) carries the genetic code from the DNA, and is the template for protein translation.

(b) Transfer RNA (tRNA) is the key to deciphering the genetic code and each tRNA molecule contains an anticodon that pairs with the appropriate codon in the mRNA. tRNAs with a particular anticodon are attached to a specific type of amino acid, which the tRNA carries to the ribosome.

(c) Ribosomal RNA (rRNA) is a structural constituent of the ribosome, a large complex of proteins and rRNA molecules. The large subunit contains two different ribosomal RNAs in prokaryotes and three in eukaryotes, while the small subunits contain one ribosomal RNA. Ribosomes bind to the mRNA, detect the initiation codon (5′ –AUG– 3′), and move along the mRNA translating the codons to synthesise a polypeptide.

Answer to SAQ 19

You may have thought of some of the following:

1. In prokaryotes, gene transcription occurs in the cytoplasm, whereas in eukaryotes transcription occurs in the nucleus.
2. Therefore in prokaryotes, transcription and translation take place simultaneously in the cytoplasm (whereas eukaryotic mRNA must be exported from the nucleus before translation can take place).
3. In prokaryotes, the primary RNA transcript needs no modification and is immediately ready for translation, while in eukaryotes, the primary transcript requires extensively modification (by intron splicing, capping and polyadenylation) to produce a mature mRNA suitable for translation.
4. In prokaryotes, all RNAs are transcribed by a single type of polymerase. In contrast, there are three types of RNA polymerase (I, II and III) in a eukaryotic cell. RNA polymerase type II transcribes mRNA.

5. In prokaryotes, DNA is not bound to packaging proteins and is accessible to the transcription machinery. In eukaryotes, in contrast, DNA is packaged with histones, so changes in chromatin architecture are essential for the initiation of gene transcription.
6. Prokaryotic RNA polymerase binds directly to a gene's core promoter, consisting of two sets of consensus sequences, the −10 and −35. In contrast, eukaryotic RNA polymerase cannot bind directly to the equivalent 'TATA box' (−25 to −35) in a promoter. Instead, general transcription factors must assemble with RNA polymerase at the promoter to initiate transcription.
7. Gene transcription is regulated by the binding of transcription factor proteins to the DNA in both prokaryotes and eukaryotes, but eukaryotic genes have a greater number and range of DNA regulatory sequences spread over a wider area. In prokaryotes, transcriptional activators and repressors bind to regulatory sequences close to the promoter to regulate the transcription. In eukaryotes, regulatory transcription factors bind to regulatory sequences that occur 100–200 base pairs upstream of the promoter, but there are also regulatory DNA elements (enhancer and repressors) that can be many tens of thousands of base pairs away from the promoter.
8. In prokaryotes two or more genes encoding proteins with related functions are often arranged in a unit known as an operon, where they are transcribed under the control of a single promoter into a single polycistronic mRNA. In eukaryotes, individual genes are transcribed from their own promoter.

Answer to SAQ 20

(a) and (c) are false

(a) is false – only in the cleavage divisions of the cells of very early embryos does mitosis occur as soon as DNA replication has finished. In other cells, the period known as G2 occurs between DNA replication and mitosis.

(c) is false – the converse is true; cells pass from G1 through S, then G2 and finally M. DNA replication occurs during the S phase, so during G2 the DNA content of cells is twice that of the same cells in G1.

Answer to SAQ 21

Statements (b), (e) and (f) are true.

Statement (a) is false. As well as linking different parts of a single folded polypeptide, disulfide bonds can form between subunits in multimeric proteins, stabilising the quaternary structure.

Statement (c) is false. Cytosolic polypeptides will fold such that hydrophobic residues are, as far as possible, buried in the interior of the protein.

Statement (d) is false. Chaperones, not histones, enable misfolded or unfolded proteins to refold correctly. Histones are involved in packaging DNA.

Answer to SAQ 22

Statements (d) and (e) are true.

(a) is false. Enzymes lower the energy barrier presented by the reaction.

(b) is false. Most enzymes function within in a narrow temperature range.

(c) is false. Enzymes are unchanged by the reactions that they catalyse.

Answer to SAQ 23

According to the fluid-mosaic model, the basic structure of the membrane is a fluid lipid bilayer with membrane proteins that are either embedded in or attached to it. The lipids and proteins of the membrane are highly mobile in the plane of the membrane.

Answer to SAQ 24

Integral membrane proteins have some portions that interact with the hydrophobic core of the lipid bilayer. Some cross the lipid bilayer (transmembrane proteins) whilst others protrude one side of the membrane. Peripheral membrane proteins either associate with the membrane indirectly via non-covalent interactions with other membrane proteins, or directly via interactions with the hydrophilic head groups of the lipids. Lipid-linked membrane proteins are attached via a covalent link to a lipid in the inner or outer leaflet of the membrane.

Answer to SAQ 25

Cortisol (c) is a non-polar organic molecule to which the lipid bilayer is very permeable; likewise, the small NO gas molecules (d) readily diffuse across membranes. Amino acids (a) and sugars (b) are both polar molecules, so their transfer across membranes requires the agency of protein channels or carriers.

Answer to SAQ 26

Carriers (transporters) and channels are membrane proteins that control the movement of small polar molecules and ions both across the cell membrane and across intracellular membranes. A carrier binds to a specific solute molecule or ion and releases it on the opposite side of the membrane. A channel provides a pore in the membrane through which a specific solute can pass. Channels allow only passive movement of solute (i.e. facilitated diffusion), but there are both active (ATP-requiring) and passive carrier transport processes.

Answer to SAQ 27

(a) Secreted signalling molecules diffuse to the target cell where they bind to a specific receptor in the surface or, in the case of lipid-soluble signals, inside the cell and thereby elicit a response. In contrast, cell–cell contact-dependent signalling requires the signalling and target cells to be in direct contact. This can either occur by the use of gap junctions to connect the cells or by the use of a membrane-bound signalling molecule on one cell that binds to a membrane-bound receptor on the target cell.

(b) Paracine signalling involves the release of a signalling molecule that acts locally on surrounding cells whereas in autocrine signalling, the signalling molecule acts on the cell from which it was released.

Answer to SAQ 28

(a)

i. Ion channel-linked receptor. (An example of a ligand that activates this type of receptor is acetylcholine).

ii. G protein-coupled receptor. (Examples of ligands that activate this class of receptors are adrenalin/noradrenalin and yeast mating factors).

iii. Enzyme-linked receptor. (Examples of ligands that activate this class of receptors are cytokines and growth factors).

(b) Nitric oxide and small nonpolar organic molecules, such as steroid hormones, can diffuse though the cell membrane and act on intracellular receptors. Signalling molecules, such as those mentioned in (a) that bind to cell surface receptors, are hydrophilic molecules and cannot diffuse through the cell membrane.

Answer to SAQ 29

A = glucose

B = pyruvate

C = pyruvate

D = acetyl CoA

E = NADH

F = NADH + $FADH_2$

Answer to SAQ 30

(a) Glycolysis

(b) The mitochondrion

(c) ATP stores energy either absorbed from light via pigments or released from nutrients such as glucose or lipids by the process of cellular respiration. ATP can be thought of as an ‘energy currency’ of the cell.

Answer to SAQ 31

So bacterial cells carrying the plasmid can be identified and isolated. The presence of an antibiotic resistance gene (e.g. tetR) on the plasmid means that only cells carrying that plasmid (and expressing that gene) can grow on media impregnated with that antibiotic (tetracycline).

Answer to SAQ 32

(a) Double immunolabelling of tissue sections (immunohistochemistry).

(b)

(i) Specific antisera that recognise each of the two molecules (one that recognises insulin, and a second that recognises trypsin).

(ii) Two secondary antisera coupled to two different fluorescent markers (or enzymes that produce different coloured reaction products).

Cells that contain both molecules would be 'double labelled', while those that contain only one of the two molecules would display a single fluorescence (or colour reaction). Note that this technique does not prove that these molecules are synthesised in these cells. In order to demonstrate the synthesis of a molecule unambiguously, it would be necessary to examine the mRNA content of the cells.

Answer to SAQ 33

The three steps are:

Step 1: denaturation in which the DNA is placed at a very high temperature (94°C) in order to separate (denature) the two DNA strands.

Step 2: primer annealing in which the temperature is lowered (to 55 °C) to allow short DNA primers to bind to the DNA strands.

Step 3: elongation in which a DNA polymerase synthesises a DNA strand by adding nucleotides to the 3′ end of the primer, using the original DNA strand as a template. The temperature of 72 °C is optimal for the activity of the thermostable Taq polymerase commonly used in PCR reactions.

Answer to SAQ 34

10 nm, 0.1 μm, 0.0001 m, 1 mm

Answer to SAQ 35

(a) 3.5×10^{-10} mol l^{-1}

(b) 3×10^{-4} mol s^{-1}

Answer to SAQ 36

1 : 256.

The probability of drawing a yellow marble is 1 in 4; and the probability for each of the other three colours is also 1/4. So the probability of drawing them in this sequence of four is

¼ × ¼ × ¼ × ¼ = 1/256

Answer to SAQ 37

0.29 g.

Mass concentration = molar concentration × relative atomic mass

= 0.5 × 58.44 g 1^{-1}

So in 10 cm^3 (= 0.01 litre), the mass of NaCl = 0.5 × 58.44 × 0.01 g

= 0.2922 g = 0.29 g (2 sig figs).

Answer to SAQ 38

A is correct.

The *t*-test is the most appropriate test to use when you are testing whether the difference between the means of two datasets that are normally distributed is significant.

The *t*-test requires three pieces of information from each compared set of data. These are the mean, the standard deviation and the sample size. The value of *t* is compared to a table of critical values to determine whether it is significant.

Answer to SAQ 39

C is correct.

If the question being asked is whether there are associations between datasets then the Chi-squared test or the Spearman rank correlation might be appropriate.

The Chi-squared test is suitable to use when you want to assess the significance of an association between the datasets the data you have are obtained by defining particular categories or classes to which individuals belong (such as present/absent). The Chi-squared test is also suitable when investigating whether the frequency of an observed event differs from its expected frequency.

The starting point is a null hypothesis of there being no association between the datasets.

Answer to SAQ 40

(a) No. The error bars overlap and therefore any apparent difference could well be due to chance.

(b) There would be selection pressure for plants able to allocate more resource to root production under these conditions because if water or nitrogen availability is limiting growth, plants with larger root systems that cover more soil area and capture more of the resource would be at an advantage.

(c) The value for *L. multiflorum* is lower, indicating it allocates more of its resource to shoot production. This allocation pattern suggests the plant has become adapted to situations where soil resources are not limiting growth and therefore resource is preferentially allocated to producing leaves to capture more light, which would then become the limiting resource.

Answer to SAQ 41

Primary literature refers to an original research article: the scientists' own account of a particular study. It includes details of experimental procedures, analysis of results, interpretation and discussion of findings in wider context and cites relevant papers from other authors and generally conforms to a standard format – Abstract, Introduction, Materials and Methods, Results, Discussion, References.

Answer to SAQ 42

Peer reviewers assess and comment on (i) the quality of the research and the paper, (ii) the relevance of the research to the journal, (iii) the importance or significance of the research.