



2024 VCE Biology external assessment report

General comments

The length of the examination was appropriate and gave students the opportunity to complete the paper in the time available.

In Section A, the multiple-choice questions provided students with a variety of question styles, formats, amounts of reading, and levels of difficulty.

Students should use the reading time to consider the Section B questions, identify the key information required, and start formulating their answers. Notwithstanding handwriting size, the number of lines under a question gave an indication of the amount of space required to answer it.

In Section B, many students produced responses of a high standard and it was clear that they had read the questions carefully and planned their answers prior to writing. Answering in dot points is acceptable and can help students to ensure they are addressing all parts of a question; this was an issue in Question 4c where many students only addressed the second part of the question. Students should use the number of marks as an indication of the level of detail required in their response. For example, Question 4a required students to provide three different reasons for why photosynthesis can be considered a biochemical pathway.

When a question asks students to provide an explanation, it is important that they provide extra information to demonstrate their knowledge rather than just repeating information from the question stem. This was a common error in Question 5a.ii, where many students only discussed the environmental benefit of using less nitrogen fertiliser rather than the impact on the plant if more nitrogen was available. Students should familiarise themselves with the VCAA [glossary of command terms](#), such as 'compare', 'justify' and 'outline', to ensure their response specifically addresses the question.

Students are advised to incorporate biological knowledge when answering questions; for example, in Question 5a.ii they could do so by connecting chlorophyll to its role in the light-dependent stage of photosynthesis. Students are encouraged to relate their answers to the context of the question, rather than simply repeating pre-planned responses. This was seen in Question 8c.ii, with many students providing a pre-planned speciation response, whereas the question required students to discuss what led to the genetic diversity between two already separate groups/populations.

Students should ensure they are familiar with the key science skills, as these were assessed in multiple ways across the examination (such as in Section A Questions 18, 23 and 24, and in Section B Questions 1e, 10c.i and 10c.ii). The use of a ruler (one of the basic stationery items allowed in all exams) would assist students with reading graphs accurately, which was a requirement for Section B Questions 4b, 5a and 10a.

The 'extra space for responses' pages at the back of the Question and Answer Book provided students with a designated place to continue their responses if they needed to elaborate further or provide a revised response to their original. On many pages, there was also blank space with no lines under the question, such as after Questions 8c.ii and 9d. Students could use this space instead of, or in addition to, the space at the back. If students chose to use the extra space, they had to clearly indicate this in their response.

Specific information

This report provides sample answers or an indication of what answers may have been included. Unless otherwise stated, these are not intended to be exemplary or complete responses.

The statistics in this report may be subject to rounding, resulting in a total of more or less than 100 per cent.

Section A – Multiple-choice questions

The table below indicates the percentage of students who chose each option. Grey shading indicates the correct answer.

Question	Correct answer	% A	% B	% C	% D	Comments
1	A	90	5	3	2	As the molecule had a quaternary structure, it is a protein. As such, its monomers are amino acids.
2	D	2	10	3	84	RNA is typically a single-stranded molecule composed of nucleotide monomers, which contain a ribose sugar and the nitrogenous bases adenine, cytosine, guanine and uracil. mRNA, a type of RNA, carries instructions for the synthesis of proteins to the ribosome.
3	B	13	56	19	12	In attenuation, RNA polymerase begins to transcribe the leader region of the <i>trp</i> operon, which lies before (upstream of) the five structural genes and, at the same time, translation of the leader region mRNA by the ribosome begins. When <i>trp</i> concentrations are high, the ribosome detaches from the leader region mRNA strand, transcription stops prematurely and the five structural genes encoding the five enzymes that are used to produce <i>trp</i> are not expressed. Attenuation occurs when the repressor protein is not bound to the operator region (i.e. when repression is not occurring), so options C and D are incorrect.
4	D	21	10	8	61	Option D shows the correct structure of a eukaryotic gene, which contains a promoter sequence at the start and a terminator sequence at the end. Eukaryotic genes do not have an operator region; only prokaryotic operons contain an operator region, therefore option A was incorrect.
5	A	65	12	14	9	Foreign DNA from bacteriophages is inserted as spacers between the CRISPR repeats to provide a memory of the virus in the event the bacterial cell is reinfected by the same virus, so option A is correct. The PAM sequence is adjacent to the target DNA, not to the repeats in the CRISPR array, so option B is incorrect. Option C is incorrect, as it incorrectly refers to Cas9 proteins being transcribed. DNA/genes are transcribed and proteins are translated. Option D is incorrect, as the <i>cas</i> operon would be transcribed to produce crRNAs, not translated.
6	B	5	84	4	7	The CRISPR-Cas9 system in prokaryotes (bacteria) acts like the adaptive immune system in humans, remembering specific viruses (such as bacteriophages) if they infect cells.

Question	Correct answer	% A	% B	% C	% D	Comments
7	A	69	19	2	10	The canola plant has been genetically modified as it contains genes from cress plants. Thus the oil it produced could also be considered genetically modified. Option B was the most common incorrect answer. It incorrectly stated that <i>Agrobacterium</i> recombinant plasmids would be incorporated into the cress plant genome, whereas genes from the cress plant were inserted into the <i>Agrobacterium</i> recombinant plasmid, and subsequently this was inserted into the canola plant.
8	B	26	64	4	6	Students were required to recall the respective locations of the Krebs cycle and electron transport chain in mitochondria. This included determining their locations from diagrams of the organelle. Location 1 (option A) showed the cristae or inner mitochondrial membrane, which is the site of the electron transport chain, not the Krebs cycle. Location 2 (option B) showed the mitochondrial matrix, which is the location of the Krebs cycle.
9	A	52	18	23	7	Location 1 is the cristae or inner mitochondrial membrane, where the electron transport chain occurs, producing a high amount of ATP (26 or 28 ATP). Location 2 is the mitochondrial matrix, where the Krebs cycle occurs, producing a low amount of ATP (2 ATP). Location 3 is the region outside of the mitochondrion, the cytosol, where glycolysis occurs, producing a low amount of ATP (2 ATP). Location 4 is the outer mitochondrial membrane, which does not produce any ATP. Students who had difficulty with Question 8 may have also found Question 9 challenging. Students may have confused the outer mitochondrial membrane (location 4) as the site of the electron transport chain, which produces the most ATP; however, this stage occurs at location 1.
10	D	2	9	4	85	Lactic acid is a product of anaerobic respiration (anaerobic fermentation) in animal cells. Anaerobic respiration occurs when oxygen is absent or in low concentrations.
11	C	7	7	77	10	Students were required to recall the inputs and outputs of each stage of aerobic cellular respiration, one of these being the electron transport chain. In this stage, water and (26 or 28) ATP are produced, along with the unloaded coenzyme NAD ⁺ which is cycled back to either glycolysis or the Krebs cycle to accept more electrons and hydrogen ions. Therefore, option C is correct.
12	D	9	2	2	86	Option D was the only correct response, as when microalgae were exposed to white light conditions, there was an increase in cell density on each day measurements were recorded.
13	C	2	2	84	12	The correct controlled variable was the light intensity of all the different lights (option C). The microalgae under investigation in this experiment would all have slight variations in the relative amount of chlorophyll molecules present in each algal cell, due to natural variation between cells. Therefore, option D is incorrect.

Question	Correct answer	% A	% B	% C	% D	Comments
14	A	77	20	1	2	The light-dependent stage of photosynthesis occurs at the thylakoid membrane, or grana (option A). This is the stage where reactant water molecules are split into oxygen and hydrogen ions and electrons (both collected by NADP ⁺ to form NADPH). The stroma is where the light-independent stage occurs, which does not directly rely on light energy; therefore, option B was incorrect. Students are required to know the locations, inputs and outputs of the various stages of both photosynthesis and cellular respiration.
15	C	5	10	68	17	Students should know that both oxygen and carbon dioxide can bind to the active site of the Rubisco enzyme. However, as the temperature increases, carbon dioxide is less likely to bind to Rubisco. Therefore, the rate of carbon fixation is slower at 40 °C compared to 20 °C, making option C correct. Option D is incorrect because as temperature increases, the likelihood of oxygen binding to Rubisco increases, not decreases.
16	D	6	8	15	72	Bioethanol is produced by yeast and microorganisms via fermentation, which also produces carbon dioxide. Cellulose, a component of the cell wall of plants, would be a suitable source of biomass. Option C is incorrect because in biochemical pathways, different enzymes are used to catalyse each step.
17	C	10	23	58	9	Signalling molecules (such as histamine) are produced by mast cells and act on blood vessels to produce the heat and swelling involved in the inflammatory response, as correctly outlined in option C. Students who chose the incorrect option B may have only read the first part of the answer, that 'inflammation is an innate immune response', which is a correct statement. However, crystals of urate are also present in the joints of healthy individuals, they just build up during gout attacks, making option B incorrect.
18	A	68	12	13	6	Only options A and B identified a correct type of study for this investigation. However, in this investigation primary data was collected by researchers, making options B and D incorrect. Furthermore, option C is incorrect, as participants deciding on the frequency rating of attacks for themselves is not categorised as an ethical standard.
19	A	55	22	19	3	Complement proteins are part of the innate immune response, present in the blood in an inactive form until a foreign pathogen/antigen triggers an immune response; therefore, option B is incorrect. Complement proteins enhance the inflammatory response as they assist with attracting phagocytes to the site of infection, making option A correct. While complement proteins can be activated by helper T cells, which can lead to the formation of a membrane attack complex (MAC), resulting in cell death, option C does not specify if the cell death is of the pathogen or the body's own cells. Therefore, option C is incorrect.

Question	Correct answer	% A	% B	% C	% D	Comments
20	B	8	59	22	11	<p>While both neutrophils and dendritic cells act as phagocytes, neutrophils do not commonly behave as antigen-presenting cells and therefore usually do not present antigen fragments on their MHC Class II markers. This means options A and C are incorrect.</p> <p>Neutrophils secrete chemicals that kill pathogens, whereas dendritic cells do not, making option B correct. Dendritic cells can secrete interferons, a type of cytokine (chemical signalling molecule); however, these do not directly kill pathogens. Instead, they help to recruit other innate and adaptive immune cells. Therefore, option D was incorrect.</p>
21	A	67	11	9	12	Option A is correct because one role of the lymphatic system is to transport B and T lymphocytes to sites of infection.
22	C	10	17	70	3	<p>Option A is incorrect, as this strategy results in active, artificial immunity.</p> <p>Option B is incorrect, as this strategy results in passive, artificial immunity.</p> <p>Option C is correct, as this strategy results in passive, natural immunity.</p> <p>Option D is incorrect, as this strategy does not result in any type of immunity.</p>
23	D	6	5	2	88	Option D is correct because it is a measurement of mass, which is classified as quantitative data and, as the students are directly collecting the data, it is primary data.
24	D	7	5	8	80	Reproducibility is the closeness of the agreement between the results when an investigation is carried out under changed conditions of measurement. Changed conditions may include a different method of measurement, different observer, different measuring instrument, different location, different conditions of use, and different time.
25	C	11	5	77	6	The diagram shows a receptor on cell type 1 binding to a foreign antigen being presented by an antigen-presenting cell, and subsequently cell type 1 activates cell type 2. This suggests that cell type 1 is a helper T cell.
26	B	10	65	5	20	The diagram shows cell type 1 (a helper T cell) releasing signalling molecules (cytokines) to activate cell type 2 (cytotoxic T cells). Cytotoxic T cells are involved in the cell-mediated adaptive immune response and induce apoptosis in infected cells; therefore option B is correct. Option D is incorrect, as infected cells display foreign antigens on their MHC Class I markers. Only professional antigen-presenting cells such as dendritic cells, macrophages and B cells have MHC Class II markers. Option A is incorrect, as it is cytokines rather than antibodies that activate cell type 2.
27	D	15	11	5	69	The role of antigen-presenting cells is to transport foreign antigens to the lymph nodes, where they are then presented to specific T helper cells (cell type 1). Thus, antigen-presenting cells are most likely to come into contact with cell type 1 in the lymph nodes. This means option D is correct.
28	A	79	7	12	2	The independent variable (variable that was changed) was the method of selecting mice to return to each cage, and the dependent variable (variable that was measured) was the length of the tibia. Thus option A is correct.

Question	Correct answer	% A	% B	% C	% D	Comments
29	B	48	27	6	19	Option A is incorrect, as gene flow is the exchange of alleles through interbreeding between two different populations of mice and in this investigation the cage X and cage Y mice were separated so there was no opportunity for them to interbreed. Option C is incorrect, as allopatric speciation occurs when a population becomes geographically separated and evolves into a new species. In this investigation the two populations are separated; however, they are still the same species. Option D is incorrect, as the investigation does not identify any external environmental selection pressures (food availability, predators, etc.) that either group of mice were subjected to that would favour different tibia lengths. Option B is correct because the randomness of the mice selected could be seen as random mating, which could imply a genetic drift event. Moreover, changes in a population's allele frequencies over time due to chance (genetic drift) would be more likely in a small population like this.
30	D	7	3	12	78	Mice in Cage Y were subject to selective breeding, where the scientists manipulated the gene pool using non-random mating by determining which mice (those with longest tibias) were returned to the cage to produce the next generation.
31	C	3	11	84	2	As depicted in the diagram, the oldest fish group (jawless fish) evolved more than 485 million years ago.
32	C	20	21	55	4	Option A is incorrect because, while carbon-14 dating is a type of absolute dating, it is only suitable for fossils less than approximately 50 000 years old and the spiny shark fossils are at least 300 million years old. Option B is incorrect because while transitional fossils can help us to determine evolutionary sequences and relationships, they do not provide information about the relative age of a specific fossil. Option C is correct, as we can use faunal (fossil) succession and stratigraphy to determine the relative age of the spiny shark fossils based on rock layers. Option D is incorrect, as any comparison between fossils would be relative dating and not absolute dating, and muscle tissue would not be present in the spiny shark fossils. While the term 'law of superposition' used in option C may have been unfamiliar to students, options A, B and D could all be eliminated as incorrect, leaving option C as the only correct answer.
33	B	8	68	16	9	Antigenic drift refers to small gradual changes in viral surface antigens that can affect immunological memory from previous infections. Antigenic shift refers to sudden major changes that can occur when two different strains from different animals infect the same host cell and can result in a new set of surface antigens. Option B is correct because antigenic drift in influenza C would mean that humans may not have pre-existing immunity to the new sub-strain and so public health measures would be required to prevent an outbreak. Options A and C can be eliminated because both relate to a new strain of influenza that can infect multiple host types, which is a result of antigenic shift, not antigenic drift. Similarly, the major changes to the antigen outlined in option D would be a result of antigenic shift rather than antigenic drift.

Question	Correct answer	% A	% B	% C	% D	Comments
34	B	4	85	2	9	The image depicts the pelvis structure becoming less prominent over time as dolphins evolve; thus the pelvis bones demonstrate vestigial structures.
35	B	5	69	18	7	Based on the information and image, <i>H. lar</i> can be classified as a mammal because they have fur and give birth to live young, and as a primate because they live in small family groups, have opposable thumbs and forward-facing eyes. They can be further classified as hominoids because they lack a tail and have very flexible shoulders. Since <i>H. lar</i> are not bipedal, they cannot be classified as a hominin, nor as a member of the <i>Homo</i> species. Thus, option B is correct.
36	A	89	3	7	2	Referring to the phylogenetic tree, opossums and bandicoots most recently shared a common ancestor 77 million years ago, while bilbies and numbats shared a common ancestor 63 million years ago, which is more recent. Therefore, there would have been more time for mutations to occur and more differences in DNA sequences between opossums and bandicoots than between bilbies and numbats.
37	A	68	16	12	4	Well-developed thumbs and relatively long leg length compared to arm length are characteristics observed in <i>H. naledi</i> and modern <i>Homo</i> species, making option A correct. Options B, C and D are incorrect because the long, curved fingers and wide, flat pelvis of <i>H. naledi</i> have evolved in modern <i>Homo</i> species to be fingers with reduced curvature to allow a more precise grip and a pelvis that is more bowl-shaped.
38	A and D	26	28	10	36	According to information provided that ' <i>H. naledi</i> shares common features with <i>Australopithecus</i> and modern <i>Homo</i> species': <ul style="list-style-type: none"> Option A (position 1) was accepted as correct because it can be interpreted that <i>H. naledi</i> does not necessarily need to be related to all the different species present in these hominin groups. Options B and C (positions 2 and 3) were both incorrect because <i>H. naledi</i> should appear in the fossil record around the same time as an <i>Australopithecus</i> species. Option D was accepted as correct because it is a reasonable conclusion to require more evidence to place <i>H. naledi</i> on the tree with confidence.
39	C	3	3	80	14	The measured results are not necessarily accurate, as they significantly deviate from the standard reference true values. The measured results are precise because the technician obtained very similar results each time the experiment was repeated; therefore option C is correct.
40	A	66	1	1	31	As there is no clear area around disk Q, the results suggest the bacteria can grow because they are resistant to the antibiotic on that disk; therefore option A is correct. Disks R and S have a clear area around them (labelled as 'no bacterial growth'), indicating the antibiotic is effective at stopping bacterial growth and thus the bacteria are susceptible to these antibiotics rather than being resistant; therefore option D is incorrect.

Section B

Question 1a.i

Mark	0	1	Average
%	8	92	0.9

Location W

Question 1a.ii

Mark	0	1	2	3	Average
%	18	12	22	47	2.0

The role of the Golgi apparatus in a cell is to receive proteins from the rough endoplasmic reticulum and modify and package them into vesicles to assist the proteins to be secreted/transported/exocytosed.

Student responses needed to be specific to the role of the Golgi apparatus and not a general description of the process of exocytosis.

Question 1b

Mark	0	1	2	Average
%	29	18	54	1.3

The description of the role of tRNA in the production of a protein could have included:

- carrying specific amino acids to the ribosome for translation
- that the anticodon on tRNA binds to the complementary mRNA codon
- allowing amino acids to be joined together to form a polypeptide chain.

Question 1c

Mark	0	1	2	Average
%	25	43	32	1.1

An explanation of how an enzyme catalyses the breakdown of a protein could have included:

- speeding up the rate of reaction or lowering activation energy
- the substrate binding to the complementary active site on the enzyme
- breaking peptide bonds between amino acids.

Many students simply restated the stem; statements such as 'enzymes catalyse reactions' and 'enzymes break down proteins' were not awarded marks.

Question 1d

Mark	0	1	Average
%	45	55	0.6

The description of the role of vesicles in the export of protein could have included:

- transporting the protein to the plasma membrane
- fusing with the cell membrane
- carrying the protein to/from the Golgi apparatus.

Many students incorrectly stated that the vesicle fuses with the cell wall.

Question 1e

Mark	0	1	2	Average
%	56	19	25	0.7

Example of a limitation of the model	Example of a possible solution
<ul style="list-style-type: none"> • Overly simplified, for example: <ul style="list-style-type: none"> – portrayed as a linear sequence of events – full complexity of process is not included (e.g. protein folding / gene regulation / alternative splicing) • Full genome/proteome not known in all organisms • New discoveries are made that do not fit the current model • One model cannot explain the different types of protein synthesis (prokaryotes vs eukaryotes) 	<ul style="list-style-type: none"> • Have several models / detailed descriptions • More research required / more advanced technology required • Change/refine the model based on new findings

This was a challenging question assessing the key science skill of ‘analyse and explain how models and theories are used to organise and understand observed phenomena and concepts related to biology, identifying limitations of selected models/theories’.

Many students incorrectly outlined a limitation of protein synthesis instead of a limitation of the scientific model of protein synthesis. Other common incorrect responses included the suggestion that the contributions from different scientists meant the model was not accurate or that the model was ‘open to interpretation’ (confusing it with limitations of the human fossil record classification scheme).

Students should be provided with opportunities throughout the course to investigate and apply key science skills such as those related to modelling as both a scientific investigation methodology and as a way of organising and understanding observed phenomena and concepts relating to biology.

Question 2

Mark	0	1	2	3	4	5	Average
%	16	18	15	23	18	10	2.4

Students were required to provide an appropriate description of an organism's proteome: all of the proteins produced by an organism.

The explanation of how organisms achieve such diversity in cell types then needed to reference both intestinal epithelial cells and fat cells, and could have included:

- that genes code for proteins
- a description of gene regulation
- a description of alternative splicing
- that mutations can occur that cause a different protein to be produced
- that different cells produce different proteins
- that different proteins fold differently.

High-scoring responses included a range of different explanations of how different cells can produce different proteins, making reference to both cells. Students needed to specifically refer to each of the two cells in their response to be awarded full marks. Many students did not specifically describe the proteome, as required by the question.

Question 3a

Mark	0	1	2	Average
%	64	27	9	0.5

Reasons why glucose does not reduce to zero over the 500 hours could have included:

- fermentation / glycolysis / anaerobic respiration stopping
- more time required for all the glucose to be consumed
- build-up of ethanol being toxic to yeast cells or altering the pH
- the yeast cells already meeting their ATP demands
- other limiting factors (e.g. number of yeast cells, amount of coenzyme) prohibiting further breakdown.

Many students included factually correct statements related to fermentation, but their response did not address what was being asked in the question.

Question 3b

Mark	0	1	2	Average
%	29	15	56	1.3

Adding oxygen would result in a decrease in ethanol being produced OR no ethanol being produced.

This would be due to aerobic cellular respiration occurring OR less glucose being available for (anaerobic) fermentation OR because ethanol is only produced by (anaerobic) fermentation.

Alternatively, ethanol could have continued to be produced.

This would be due to (anaerobic) fermentation still occurring in the presence of oxygen.

Students should note that even in the presence of oxygen, anaerobic fermentation still occurs. Reference to aerobic fermentation was incorrect because it contradicted the fact that fermentation is an anaerobic process.

Question 4a

Mark	0	1	2	3	Average
%	25	32	26	17	1.4

Explanations of why photosynthesis is considered a biochemical pathway could have included that:

- the outputs of one reaction are the inputs of the next reaction
- it involves a series of reactions (light-dependent stage and light-independent stage)
- it involves enzymes (e.g. Rubisco) and/or coenzymes (e.g. ADP/ATP and NADP/NADPH)
- it involves different reactions occurring in different locations (grana / thylakoid membrane and stroma)
- it is regulated by availability of reactants / concentration of products / abiotic factors.

It was common for students to specifically refer to the various inputs/outputs, stages, locations, enzymes and coenzymes involved in photosynthesis. However, some students provided a more generic response about biochemical pathways, which for this examination could also be awarded full marks.

Question 4b

Mark	0	1	2	3	Average
%	21	30	33	16	1.5

To support the statement that C4 plants growing next to C3 plants had an advantage, students could have provided any three of the following:

- specific use of data for both plants (e.g. at 400 lux, C3 plant carbon fixation rate is 90 mmol/hr; C4 plant carbon fixation rate is 150 mmol/hr)
- C4 plants fix more CO₂ (at all light intensities) than C3 plants
- C4 plants fix CO₂ at a faster/higher rate than C3 plants
- C4 plants have increased photosynthesis / growth / glucose production OR decreased photorespiration compared to C3 plants.

High-scoring responses usually included specific data from the graph and then linked this to increased carbon fixation in C4 plants and explained how this would specifically benefit these plants. Some students incorrectly wrote about C4 plants taking up more CO₂, as opposed to fixing more CO₂.

Question 4c

Mark	0	1	2	Average
%	43	44	13	0.7

CO ₂ fixation in C3 plants <u>changes</u> as light intensity changes because	CO ₂ fixation in C3 plants <u>plateaus</u> above 1700 lux because
<ul style="list-style-type: none"> the light-dependent stage is faster more water is split (in the light-dependent stage) more coenzymes/NADPH/ATP produced (that can be used for the light-independent stage / Calvin cycle) 	<ul style="list-style-type: none"> enzymes (Rubisco) involved in the light-independent stage / Calvin cycle / CO₂ fixation are saturated the maximum rate of reaction / photosynthesis / CO₂ fixation was reached a limiting factor (not light) was present Rubisco binds to O₂ OR photorespiration occurs

Students needed to answer both parts of the question to be awarded full marks. Many students addressed why CO₂ fixation plateaued but not why it initially changed as light intensity increased. Some students simply stated that as light intensity increased, CO₂ fixation increased, without explaining why or how. Some students incorrectly identified light as a limiting factor to explain why CO₂ fixation plateaued.

Question 4d

Mark	0	1	2	3	Average
%	22	14	25	39	1.8

Explanations of how C4 plants are better adapted to reducing photorespiration compared to C3 plants could have included that:

- C4 plants function better at higher temperatures than C3 plants
- Rubisco binds less to O₂ OR has a higher affinity for CO₂ in C4 plants compared to C3 plants
- CO₂ fixation occurs in bundle sheath cells in C4 plants and in mesophyll cells in C3 plants
- in C4 plants, CO₂ enters the light-independent stage / Calvin cycle with less competition from O₂ compared to C3 plants.

Students were required to make a comparison between C3 and C4 plants to be awarded full marks. A common misconception was that the bundle sheath and the mesophyll were located in different areas within the same cell or within the chloroplast. Some students confused C4 plants with CAM plants and incorrectly wrote about C4 plants closing their stomata during the day to avoid photorespiration.

Question 5a.i

Mark	0	1	Average
%	9	91	0.9

	Total chlorophyll content (mg/g)	Total nitrogen (%)
Control	1.0	0.2
Transformed	1.5	0.5

A response had to have all boxes within the table correct to be awarded the mark. In some cases, for the total nitrogen (%) of the transformed (*Hv1*) plant, students wrote the incorrect value of 0.6. Students are encouraged to bring a ruler into the examination and use it to read graphs accurately.

Question 5a.ii

Mark	0	1	2	Average
%	30	24	46	1.2

The change in either chlorophyll or nitrogen in the transformed barley plant could have impacted the plant in the following ways.

Chlorophyll	Nitrogen
Two of: <ul style="list-style-type: none"> increased light absorption / light-dependent stage increased photosynthesis / glucose production increased plant yield 	Two of: <ul style="list-style-type: none"> increased nutrients / amino acids / nucleic acids increased protein production / protein synthesis increased plant yield

Students tended to select the chlorophyll option over nitrogen, and this was easier for them to justify using their biological content knowledge. When discussing nitrogen, many students only discussed the environmental benefit of using less nitrogen fertiliser rather than the impact on the plant if more nitrogen was available. Students needed to be aware that nitrogen is a key component of nucleic acid and protein structure.

Note: 'increasing the efficiency of photosynthesis' or 'improving photosynthesis' is not the same as 'increased photosynthesis'.

Question 5b

Mark	0	1	2	Average
%	45	42	13	0.7

Explanations of why some barley seeds may not have been transformed could have included:

- not all seeds/cells incorporated the CRISPR-Cas9
- the gene may not always be edited OR off-target editing occurred
- Cas9 did not bind to the PAM sequence OR did not cut the gene
- single guide RNA (sgRNA) was not complementary to the target gene OR there was a mutation in the target gene
- the cell repaired the cut made by Cas9 without inserting the nucleotide.

It was evident that the role of different components in CRISPR-Cas9 in eukaryotic cells was not well understood by students, particularly the roles of sgRNA, Cas9 endonuclease and the PAM site. The term 'transformed' in this question was often confused with the process of 'bacterial transformation' and some students incorrectly referred to plasmids in their responses.

Question 5c

Mark	0	1	2	Average
%	11	44	45	1.4

The transformed barley plant was *Hv1-C*.

This is because *Bst*N1 did not cut the DNA of the transformed barley plant, resulting in a larger fragment present in the gel.

Students often repeated information provided in the stem to justify their selection of the transformed barley plant (e.g. *Bst*N1 has no recognition sites for DNA from transformed barley plants). Their justification needed to rely on reference to further biological knowledge, rather than simply stating that the banding pattern in *Hv1-C* did not match the control. Some students incorrectly stated that the larger fragment was due to an inserted gene in the transformed plant. However, the transformation was due to a nucleotide substitution and therefore the DNA from each plant type was the same length before exposure to *Bst*N1.

Question 5d

Mark	0	1	2	Average
%	22	27	51	1.3

DNA fragments are separated in gel electrophoresis by:

- size, as smaller DNA fragments move further/faster
- movement towards the positive electrode (as DNA is negatively charged).

The terms 'anode' and 'cathode', and their respective charges, were often confused by students. Other incorrect responses included that the larger the DNA fragment, the more negative the charge, and that the size of the gel pores decreases further away from the gel wells.

Question 6a

Mark	0	1	2	Average
%	28	24	48	1.2

Both trastuzumab and pertuzumab have the same variable regions as they are both complementary to, and therefore bind to, the HER2 receptor.

OR

Trastuzumab and pertuzumab bind to the receptor at different sites. Therefore, they are complementary to different sites and have different variable regions to each other.

Students were required to refer to both monoclonal antibodies in their responses. A common incorrect response was to state that the trastuzumab variable region bound to the cell membrane and the pertuzumab variable region did not.

Question 6b

Mark	0	1	2	Average
%	33	35	32	1.0

Identification of two ways in which the monoclonal antibodies could function to help treat a person with HER2-positive breast cancer could have included:

- binding to the receptor
- blocking the receptor OR preventing cancer cells from dividing/growing OR stopping growth factor being received
- carrying chemotherapy drugs / radioactive isotopes to cancer cells
- only targeting cancer cells OR reducing side effects by not affecting healthy cells
- opsonising/flagging cancer cells (for destruction) OR stimulating immune cells
- immobilising/reducing the spread of cancer cells.

Some students were only able to identify one way that monoclonal antibodies could function in breast cancer treatment. Students needed to refer specifically to the effect of monoclonal antibodies on cancer cells, not just on cancer.

Question 7a

Mark	0	1	2	3	Average
%	3	10	26	61	2.5

An action taken may have been vaccination. This would have increased herd immunity by reducing the number of available hosts, thereby limiting the transmission of measles. This would have led to a decrease in the number of reported cases.

Alternatively, other actions that could have been explained included the isolation/quarantine of infected individuals and increasing the education available regarding how measles infections are transmitted. These actions would have led to less transmission of measles, reducing the number of cases.

Wearing masks was not accepted as an appropriate action because the measles particles can stay airborne for many hours and (surgical) masks generally have ineffective filters. Therefore, mask wearing by the general population would not have resulted in such a rapid and prolonged decrease in the number of reported cases of measles.

Question 7b

Mark	0	1	2	3	Average
%	6	23	43	27	1.9

The potential source of the measles infection could have included an infected traveller OR an unvaccinated individual contracting/spreading measles.

Two benefits of listing the public locations could have included:

- ensuring people avoided the areas
- allowing those who visited the locations to monitor for symptoms OR get tested
- allowing people to isolate if they suspected they may be infected
- encouraging the wearing of (hospital-grade) masks
- promoting booster vaccinations.

Simply stating that an individual visited a place where measles was present was not accepted as a potential source of measles. Wearing of (hospital-grade) masks was accepted here, as this action would benefit specific individuals at risk of infection within the affected public locations.

Question 7c

Mark	0	1	2	3	4	Average
%	33	21	33	6	7	1.4

Factor	Description
Zoonosis OR increased proximity to animals OR wildlife trade	Animals passing on new pathogens to humans
Antigenic shift	Major mixing/reassortment of viruses
Climate/environmental change	The release of new pathogens (e.g. melting of polar ice caps)
Increased exploration/travel	Humans reaching uncharted areas and encountering new pathogens
Increased biotechnology	The risk of a new pathogen escaping

Each of the two factors required was awarded one mark. The respective descriptions needed to match the factor identified by students to also be awarded a separate mark each.

Antigenic drift was not accepted as a factor as this involves only gradual changes in the surface antigens, which most commonly results in a slight change to an existing pathogen, rather than the emergence of a new pathogen.

Antibiotic resistance was not accepted as this only occurs due to a mutation or modification of the genome for an existing bacterial pathogen, rather than the emergence of a new pathogen.

Question 8a

Mark	0	1	Average
%	61	39	0.4

Fieldwork OR classification and identification.

Question 8b

Mark	0	1	2	Average
%	4	31	65	1.6

Evidence that suggests the two groups of *E. salubris* are separate species could have included:

- different molecular homologies OR different DNA / amino acid sequences
- different structural morphologies OR different appearance of leaves/trees
- growth in different soil phosphorus levels
- a lack of interbreeding between the two groups.

Students often restated information from the stem of the question without clearly indicating the specific evidence that classified the *E. salubris* as separate species. For example, 'thinner leaves are only found in soils with high phosphorous levels' did not provide enough evidence as to why the two *E. salubris* groups were separate species.

Question 8c.i

Mark	0	1	Average
%	21	79	0.8

Sympatric (speciation)

Question 8c.ii

Mark	0	1	2	3	4	Average
%	13	21	22	20	23	2.2

The genetic diversity between the two groups of *E. salubris* may have been due to:

- initial variation in alleles/phenotypes
- the two groups being exposed to different selection pressures (e.g. different levels of phosphorus in the soil)
- the thinner leaf trees having a selective advantage for growing in soils with high phosphorus levels
- reduced gene flow between the two groups
- separate mutations accumulating in each group
- reproductive isolation (as a result of flowering time / pollination).

It is important that any potential misconceptions regarding genetic changes in a population over time are addressed as part of the course. Some students incorrectly included Lamarckian statements, such as suggesting the trees adapted to high phosphorus levels in the soil. Many students provided a pre-planned speciation response, whereas the question required students to discuss what led to the genetic diversity between two already separate groups/populations. The inability to breed and produce fertile offspring was not a relevant response to this question.

Question 9a

Mark	0	1	Average
%	54	46	0.5

Non-Indigenous Australians' DNA was sequenced to act as a comparison to highlight the diversity of DNA sequences within the Indigenous Australian communities.

Many responses incorrectly referenced that this would allow researchers to confirm if interbreeding occurred between Indigenous and non-Indigenous individuals.

Note: The terms Aboriginal, Indigenous Australians and First Nations Australian peoples were able to be used interchangeably in responses to Question 9.

Question 9b

Mark	0	1	2	Average
%	5	25	70	1.7

The ethical principle of respect could have been applied in this study through:

- valuing Indigenous beliefs / cultures / customs / Country and Place / heritage / kinship
- inviting Indigenous communities to take part in the research OR Indigenous individuals consenting
- following Indigenous Australians' governance and custodianship
- aligning research with Indigenous ways of knowing
- following ethical guidelines
- ensuring research was beneficial to communities.

For this question in this examination, students were able to directly quote information from the source article as part of their response.

Question 9c

Mark	0	1	2	3	4	Average
%	17	14	36	22	10	2.0

Conclusion	Data	Explanation (any one of)
Communities have highly diverse DNA sequences.	46% variation (of 0.4% DNA sequenced) within a community OR Highest amount of sequence variation outside of Africa	<ul style="list-style-type: none"> Population has a large gene pool / size Genetic drift occurred within population Has been time for mutations to accumulate Frequent changes in selection pressures or environment occurred
There are different DNA sequence variations across communities.	2.8% variation (of 0.4% DNA sequenced) between communities OR Highest amount of sequence variation outside of Africa	<ul style="list-style-type: none"> Has been time for mutations to accumulate Limited gene flow / interbreeding / migration between communities Different communities exposed to different selection pressures or environments

Data had to include more than just numbers as it needed to relate to the difference between individuals **within** a community (first row of table) compared to individuals **between** different communities (second row of table).

Question 9d

Mark	0	1	2	Average
%	50	36	15	0.7

Explanations of how the study has contributed to advancing the understanding of human genomic diversity or treatment of genetic disease could have included:

- all four communities sharing a common ancestor
- more DNA variation being observed in Indigenous individuals than anywhere outside of Africa
- the knowledge that DNA mutations accumulate over time
- gene flow stopping before the geographical isolation of the communities
- rethinking the human migration timeline/path
- identifying unknown genetic diseases
- determining whether one community was more prone to genetic disease than others
- providing earlier or more relevant treatment OR the discovery of new treatments
- tracing the origin of genetic disease over time.

Students could also have referred specifically to data provided in the source information or phylogenetic tree or made a correct comparison between specific Indigenous communities.

Students who chose to discuss the advancement of the understanding of the treatment of genetic disease found it easier to reach more justifiable conclusions, and were often then awarded higher marks, compared to those who chose to discuss the advancement of the understanding of human genomic diversity.

For this question in this examination, students were also able to provide one advancement for the understanding of human genomic diversity and one advancement for the understanding of the treatment of genetic disease, and subsequently be awarded full marks.

Question 10a

Mark	0	1	2	3	Average
%	4	4	11	82	2.7

Examples of suitable analysis included:

- Group A reported 2.5 (slightly/somewhat likely) or the lowest likelihood of getting vaccinated
- Group B reported 3 (somewhat likely) or the second highest / lower likelihood of getting vaccinated
- Group C reported 3.5 (somewhat likely/likely) or the highest likelihood of getting vaccinated
- Groups A and B both reported between slightly likely and somewhat likely or their average likelihood was between 2 and 3
- the group that received the least amount of information was the least likely to get vaccinated
- the group that received information on individual benefits had an increased likelihood of getting vaccinated
- the group that received information on herd immunity had the highest likelihood of getting vaccinated
- groups that received any additional information had an increased likelihood of vaccination.

This question was well answered. Common incorrect responses included students not providing sufficient detail in their analysis or linking the number on the graph to an incorrect context (e.g. 3.5 does not mean 3.5 people or 3.5%, it means 3.5 average likelihood (out of 5) of getting vaccinated).

Question 10b.i

Mark	0	1	Average
%	12	89	0.9

Improve education or promote/advertise information about the benefits of vaccination (such as herd immunity, population/individual benefits and preventing illness).

Some students simply identified 'strategy C' or 'strategies B and C', which were also acceptable responses.

Question 10b.ii

Mark	0	1	Average
%	48	52	0.5

Acceptable other strategies included:

- free/subsidised vaccination
- mandatory vaccination / school vaccination program / no jab no play
- financial incentives to individuals who are vaccinated (e.g. rebates/vouchers)
- restriction on travel / banned from public places (e.g. cinemas).

A common incorrect response to this question was to propose a second strategy that was also linked to the student's findings from their student-designed scientific investigation, that is, a strategy that related to improving education about vaccines or promoting/advertising the benefits of vaccines. This was not awarded marks as the question specifically asked for another strategy, which therefore needed to be unrelated to the acceptable responses for Question 10b.i.

Question 10c.i

Mark	0	1	2	Average
%	32	63	5	0.8

An outline of the importance of randomly placing participants into groups could have included:

- decreasing bias by reducing the effect of different opinions (ensuring that individuals' pre-existing beliefs were evenly distributed across groups)
- increasing validity by ensuring the only difference between groups was the information they received (minimising the impact of individual differences between participants)
- increasing repeatability by ensuring groups were more likely to be representative of the population (increasing the diversity of each group in terms of age/gender/background).

This was a challenging question and while many students used a range of terms from the key science skills, very few were able to apply these in the context of the investigation and the importance of random placement of participants.

Question 10c.ii

Mark	0	1	2	Average
%	28	55	17	0.9

The investigation was **valid** because:

- a large sample size was used
- responses were anonymous
- it measured what it aimed to measure (or a description of this) OR only one variable changed between groups (the information received between groups was the only independent variable)
- Group A acted as a control/comparison for Groups B and C
- the same information was given to all participants in the **same group**.

'Participants were randomly placed into groups' was not an acceptable response, as outlined in the stem of the question.

OR

The investigation was **not valid** because:

- the participants were from a limited demographic (linked to school / community / social media)
- it did not measure what it aimed to measure (or description of this) OR more than one variable was changed between groups (more than one independent variable)
- there was no control group of participants not receiving any information on vaccination
- previous education/literacy levels of individuals or previous knowledge/education about vaccinations was not accounted for
- the data collected was subjective/qualitative or the online nature of responses was difficult to verify.

Students could also identify the investigation as somewhat valid and provide any two relevant points from either list above. Students needed to comment on the validity of the results within their response to be awarded maximum marks.

It was evident that many students did not have a strong grasp of the specific meanings of each of the data and measurement terms in the study design, such as 'accuracy', 'repeatability', 'validity' and 'precision', which were often used in incorrect contexts. Students should be provided with opportunities throughout the course to investigate and apply the key science skills to a range of scientific investigation methodologies as well as a range of biological contexts and scenarios.