Year 12 Biology Modules 5 and 6: Heredity and Genetic Change

## Table of contents

[Year 12 Biology Modules 5 and 6: Heredity and Genetic Change 1](#_Toc42260245)

[Table of contents 2](#_Toc42260246)

[The Year 11 course 3](#_Toc42260247)

[Course overview 4](#_Toc42260248)

[Module 5 and 6 summary 5](#_Toc42260249)

[Big ideas 5](#_Toc42260250)

[Relationship to other modules in the syllabus 6](#_Toc42260251)

[Core concepts 6](#_Toc42260252)

[Opportunities for extending concepts 7](#_Toc42260253)

[Alternative and misconceptions 8](#_Toc42260254)

[Conceptual difficulties 10](#_Toc42260255)

[Suggested teaching strategies 11](#_Toc42260256)

[IQ 5-1: How does reproduction ensure the continuity of the species? 11](#_Toc42260257)

[IQ 5-2: How important is it for genetic material to be replicated exactly? 12](#_Toc42260258)

[IQ5-3: Why is polypeptide synthesis important? 13](#_Toc42260259)

[IQ 6-1: How does mutation introduce new alleles into a population? 14](#_Toc42260260)

[IQ 5-4: How can the genetic similarities and differences within and between species be compared? 15](#_Toc42260261)

[IQ 5-5: Can population genetic patterns be predicted with any accuracy? 16](#_Toc42260262)

[IQ 6-2: How do genetic technologies affect the Earth’s biodiversity? 17](#_Toc42260263)

[IQ 6-3: Does manipulation of DNA have the potential to change populations forever? 17](#_Toc42260264)

[Resources 22](#_Toc42260265)

[General resources 22](#_Toc42260266)

[IQ 5-1: 22](#_Toc42260267)

[IQ 5-2 23](#_Toc42260268)

[IQ 5-3 23](#_Toc42260269)

[IQ 6-1 23](#_Toc42260270)

[IQ 5-4 24](#_Toc42260271)

[IQ 5-5 24](#_Toc42260272)

[IQ 6-2 and 6-3 25](#_Toc42260273)

[Appendix 1 28](#_Toc42260274)

[Appendix 2 28](#_Toc42260275)

## The Year 11 course

During the teaching of the Year 11 course, it is expected that students have been provided opportunities to develop all seven of the Working Scientifically skills. Ideally, these would be embedded into the teaching of the Knowledge and Understanding components of the course, which allows students to develop a sound knowledge of the structure and function of living things, from the sub-cellular level through to the ecosystem level. In preparation for the Year 12 course, students in Year 11 could benefit from work that engages them in the following areas:

* Propose hypotheses and design and conduct valid and reliable practical investigations that enable the collection and analysis of data. Teachers should look for opportunities to engage students in these beyond where the syllabus explicitly states the need to conduct a practical investigation.
* Collect and analyse data from primary and secondary sources, including tables and graphs. It is important that students are proficient in these areas, as there is a considerable focus on population studies of genetics and disease (epidemiology) in the Year 12 course.
* Assess the uses, benefits and limitations of various types of scientific models. Many of the biological processes that are investigated occur on a cellular or molecular level (e.g. DNA replication) or happen over a long time period (e.g. evolution). Models help us to better understand these types of processes.
* Determine the impacts of various technologies in improving the understanding of various concepts, including ideas around evolution, microscopic life and processes that occur on a molecular level.
* Collect relevant information from secondary sources and determine the accuracy, reliability and validity. Many of the investigations will require students to obtain information from the Internet or other sources. Students will benefit from learning how to access the correct sort of information. They will appreciate how new evidence can change prevailing views about biological concepts developed in Year 12, including genetics, biotechnologies and diseases.
* Biology can often be best understood through the lens of evolution. Students should develop a deep understanding of the concept that all species are related through sharing a common ancestor, and patterns can therefore be observed in the living world. This will be essential to appreciate heredity and genetic processes, manipulation of genetic material, the concept of biodiversity and the understanding of diseases which are all covered in the Year 12 course.
* Construct labelled diagrams, flowcharts and other methods of communicating information. This skill is important to develop when students in Year 12 use pedigrees and Punnett squares, negative feedback loops or outline aspects of the immune response.
* Understanding of biological processes has been significantly impacted upon by societal, cultural and economic factors. Students should be provided opportunities to engage in work that allows them to acknowledge these influences.
* Develop a deep understanding of the impacts of humans on ecosystems and an appreciation of the importance of sustainability in its various forms. This includes understanding the roles of Aboriginal and Torres Strait Islander Peoples in caring for Country and Place.

## Course overview

The Year 12 course follows some major themes that weave throughout all modules. These include:

* **Survival:** Individuals and populations have strategies that enable them to survive. Some of these include successful reproduction, metabolism, responses to infection and homeostatic mechanisms. The survival of species is reliant on genetic variation in changing environments.
* **Patterns exist in biology**: Various types of patterns can be observed in the natural world. For example, the inheritance of certain traits and the occurrence of infectious and non-infectious diseases can be predicted through the observation of patterns. Although the biosphere is diverse, similarities and patterns in the molecular makeup (e.g. DNA structure) of all species can be observed and these are explained through evolution and common ancestry.
* **Technologies**: Various types, including biotechnologies, can be used to better understand biological processes. They can help us to better understand life in the past, enhance survival and quality of life in human populations, productivity and sustainability in the environment.
* **Society**: Biology is influenced significantly by societal factors. The economy, cultural influences and ethics have all played important roles in shaping how we understand the living world.

## Module 5 and 6 summary

These two modules explore the following inquiry questions:

* **IQ5-1:** How does reproduction ensure the continuity of a species?
* **IQ5-2:** How important is it for genetic material to be replicated exactly?
* **IQ5-3:** Why is polypeptide synthesis important?
* **IQ5-4:** How can the genetic similarities and differences within and between species be compared?
* **IQ5-5:** Can population genetic patterns be predicted with any accuracy?
* **IQ6-1:** How does mutation introduce new alleles into a population?
* **IQ6-2:** How do genetic techniques affect Earth’s biodiversity?
* **IQ6-3:** Does artificial manipulation of DNA have the potential to change populations forever?

Successful reproduction is imperative for species survival. These two modules investigate the various ways that cells and organisms reproduce, the mechanisms of inheritance and the role of mutation and sexual reproduction in generating variation.

Throughout history humans have manipulated the genetic make-up of individuals and populations by using selective breeding practices. Over more recent years there has been a rapid increase in our skills and knowledge of how to manipulate the genetic make-up of individual organisms at the cellular and molecular level.

Because of the interactions between these two modules and the themes that weave through them it is suggested they may be programmed together.

### Big ideas

* **Survival**: In order for a species to survive, its members must reproduce and pass on their genetic material (DNA or RNA) to their offspring. DNA changes as it replicates. These changes are called mutations. Mutations result in biological variation which can affect an individual’s and a species’ survival.
* **Patterns exist in Biology:** Patterns are evident in the structure of DNA and RNA and in the inheritance of genetic traits in individuals and populations. Studying patterns allows scientists to predict outcomes.
* **Technology and Biotechnology:** Humans use technology and biotechnology to manipulate reproduction and genetic material to enhance survival, quality of life, agricultural productivity and the environment.
* **Biology, as a science, does not exist in isolation: social**, economic and ethical issues have a significant impact on survival, the patterns that exist in Biology and the use of technologies.

### Relationship to other modules in the syllabus

Modules 5 and 6 are best delivered at the start of the Year 12 course. They may be taught sequentially, however, as there is significant overlap in the course content the writers of this document are suggesting that the two modules be combined to provide an improved flow of content. IQ 6-1 could be taught before IQ 5-5.

Some suggested areas of focus to activate prior knowledge could include:

* Similarities and differences in cellular structures of different types of cells (Module 1).
* Theory of evolution by natural selection (Module 3).

Some potential future links to other Modules in the Year 12 course could include:

* Genetic engineering procedures to prevent the spread of disease (Module 7).
* Causes and effects of genetic diseases and cancer (Module 8).
* Genetic engineering to prevent non-infectious diseases (Module 8).

## Core concepts

When exploring the inquiry questions within each module, the most important concepts that students need to develop a deep understanding of can be broken down. These include:

* Organisms reproduce sexually or asexually, which affects genetic variation.
* Asexual reproduction produces many genetically identical organisms. Asexual reproduction ensures continuity of the population when it is suited to the environment and the environment is unchanging.
* Sexual reproduction produces genetic variation within a species. Variation ensures continuity of the species in a range of changing environments.
* The nuclei of cells contain chromosomes. Chromosomes contain DNA, which makes up the genetic (hereditary) material in cells.
* Mitosis produces somatic (body) cells in an organism. All the somatic cells in an organism have the diploid number of chromosomes and contain identical genetic material.
* Meiosis produces gametes (sex cells) that contain the haploid number of chromosomes. The processes that occur during meiosis contribute to genetic variation.
* Fertilisation restores the diploid number of chromosomes. Because fertilisation is random it also contributes to genetic variation in offspring.
* DNA codes for the production of proteins through the process of polypeptide synthesis (transcription and translation).
* Mutation can occur randomly or be triggered by an environmental factor. It may or may not alter the production of proteins. In some cases, new alleles can arise and biodiversity can increase.
* Punnet squares and pedigrees can be used to display and predict some basic patterns of inheritance.
* Genetic technologies include traditional selective breeding techniques and more recent genetic engineering practices. These allow the altering of genetic information for benefits in medicine, agriculture and industry.

### Opportunities for extending concepts

These are some suggested pathways students could investigate to allow for a deeper appreciation of the inquiry questions within this module. Any extension activities should always be related to the inquiry question:

* Oogenesis and hormonal control of the menstrual cycle: Understanding these concepts could provide a deeper understanding of the timing of fertilisation and implantation. A knowledge of oogenesis would increase understanding of the process of meiosis and may also allow students to better understand why the chance of Down syndrome (Module 8) increases with maternal age.
* In-vitro fertilisation: There is plenty of information available on the web, but this is an area where teachers may have access to a health professional or someone who has undergone this procedure and is willing to talk with the students.
* Mitosis and meiosis: The processes could be described in greater detail, including names of the phases. There are many useful animations online that show the processes in detail. A thorough understanding of meiosis will assist with understanding chromosomal mutations and their effect on survival of the individual and continuity of the species.
* DNA replication could be explored in greater detail. This could include direction of synthesis (5’ to 3’ direction) leading to the production of the leading and lagging strands, Okasaki fragments and the need for ligase enzymes, the necessity of RNA primers and primase enzymes to begin synthesis on the lagging strand. There are many useful animations online showing this level of detail. This will help students understand the need for primers in PCR when looking at technologies to determine inheritance patterns in populations.
* Protein synthesis could be explored in greater detail. This could include post-transcriptional mRNA processing; the concept of coding and non-coding segments within a gene (introns and exons), splicing, as well as addition of a 5’ cap and poly-A tail. Knowledge of introns and exons will aid in students understanding of the significance of coding and non-coding DNA segments in the process of mutation.
* How mutagens operate: This could be explored in detail. This could include explanations of how ionising and non-ionising radiation, methylating agents, alkylating agents and transposons cause changes in DNA.
* Human diseases: examples or case studies of human diseases caused by point and chromosomal mutations (for example sickle-cell anaemia, Klinefelter’s syndrome, Down syndrome) could be explored according to student interest. Research may be suitable. This could be led by student interest and links well with Module 8.
* Transposons: These could be explored when assessing the significance of ‘coding’ and ‘non-coding’ DNA segments in the process of mutation.
* Non-Mendelian inheritance patterns: Additional inheritance types could be analysed, including dihybrid crosses, polygenic inheritance and linked genes.
* DNA Fingerprinting: This technique could be covered in detail as a method of determining inheritance patterns in a population. The process of gel electrophoresis could be carried out. Kits suitable for school use are available to hire or purchase.
* Hardy-Weinberg Equilibrium: This method could be explored as a way to determine allele frequencies within a population.
* Human evolution studies: Examples including mitochondrial DNA studies, Y-chromosome studies and Neanderthal DNA studies could be explored through second-hand data gathering. Students could use this information to predict a likely path for human evolution.
* Tissue cloning: a study of organoids, cell replacement therapy and/or tissue engineering therapy. Students could choose an emerging use of tissue cloning, research its use and present information on their choice to the class.
* Genetic technologies: Techniques such as CRISPR and pre-implantation genetic diagnosis and their applications could be covered in detail. This links well with prevention of inherited diseases in Module 8.

### Alternative and misconceptions

* Plants do not undertake sexual reproduction, because they don’t have sex/intercourse, yet students know that plants have pollen, bees are important and plants produce seeds (possibly produced asexually). These potential misunderstandings could be addressed with some diagnostic assessment.
* There is often a general misunderstanding of the role of hormones and the menstrual cycle, including the belief that a woman cannot fall pregnant while she has her period, or on the first time she has intercourse. It is important that the role of these hormones is established before moving onto their role in controlling pregnancy and birth.
* Students often believe that because cells in an organism are significantly different in structure and function, they contain different genetic material. Clearly stepping out the process of mitosis should help redress this misunderstanding. Looking at longitudinal sections of root tips could show how identical cells differentiate.
* Students may struggle with the concept of proteins being more than what are in foods. Revisiting enzymes and haemoglobin as examples of proteins will help to broaden their understanding of their importance to the structure and function of organisms.
* The assumption that DNA, genes and chromosomes, as terms, are interchangeable. It is important that these are defined initially and the relationship between them established.
* Mutations are harmful and/or only occur in people with deformities. This possibly stems from science fiction movies. Using the example of the Granny Smith apple or Murray Grey cattle shows that mutations can be beneficial. In most cases, mutations will have a neutral effect on the organism.
* Dominant traits are always the most common in a population. This arises because of a misunderstanding of the term ‘dominant’. Depending on the genetic trait, the recessive allele can often be more common in a population. Use Huntington’s disease as an example to demonstrate that this dominant allele is (fortunately) not the most common.
* If a couple has a “one-in-four” risk of having a child with a disease, and their firstborn has the disease, the next three children will not have the condition because the couple have already had their ‘one in four’. This is easily dispelled with a discussion about sex determination. If a couple has a boy as their first child, are they guaranteed a girl from the next pregnancy? Each fertilisation event is unrelated to all previous fertilisations. This is also true for genetic traits in other sexually reproducing organisms.
* Not knowing the difference between the terms ‘sex linked’ and ‘sexually transmitted’ may lead students to the belief that sex-linked diseases are sexually transmitted diseases. Students are usually aware that colour blindness is more common in boys than girls and it has nothing to do with unsafe sex.
* Biotechnology is a very recent development. Students don’t realise that humans have been using biological materials as tools for thousands of years. It is imperative that students are taught more traditional examples of biotechnology as well as the modern ones that involve genetic engineering. Examples include making alcoholic beer, wine, cheese, yoghurt and bread and in the last century the development of antibiotics. It also encompasses the manipulation of plant and animal breeding to increase yield as well as the more modern genetic technologies involving gene manipulation.
* Reproductive cloning will always produce an identical offspring to the parent. Phenotypic expression is the result of a combination of genotype and influence of the environment. Consider investigating examples of case studies where identical twins were raised in different environments.
* Students may hold assumptions that transgenic organisms are formed as a hybrid of two species and therefore appear as a blending of both. In reality, they only have one or a small number of genes inserted that will allow that organism to produce one or small number of different proteins. Reviewing the role of genes in coding for proteins will assist students to clarify this, and then using multiple relevant examples. Consider the ‘spidergoat’ as an example for investigation (see resources).
* Genetically modified foods are dangerous. Evidence from extensive studies by Food Standards Australia New Zealand refutes this. Golden Rice as an example of a GM food that is nutritionally beneficial.

### Conceptual difficulties

* While students understand the need for gametes to be haploid, distinguishing between the processes of mitosis (occurs in our toes) and meiosis (is needed to make eggs) is often difficult. Students making models of these processes will help their understanding of each process. Students could design a table to summarise the similarities and differences between mitosis and meiosis.
* A new area of study in this syllabus is the comparison of DNA in prokaryotes and eukaryotes. Whilst DNA is chemically the same across all organisms (as explored in Module 3), how it is structurally arranged differs between prokaryotic and eukaryotic cells. A knowledge of plasmids in prokaryotes is necessary for later work on genetic modification and of mitochondrial DNA for population genetics.
* Students will often confuse DNA replication with polypeptide synthesis. Students building models and drawing flow charts of these processes will likely help them to develop their understanding of both processes. A clear understanding the process of polypeptide synthesis is imperative to addressing the later inquiry questions about mutation and genetic technologies.
* The concept of the environment affecting phenotypic expression is not usually a difficult one, as there are plenty of examples where students can observe evidence of this happening, however, the regulation of genes for phenotypic expression is a much more difficult concept to grasp. Bozeman’s gene regulation video is a useful resource along with the use of flow charts to explain this concept.
* Students confuse co-dominance (both equally showing their full expression) and incomplete dominance (blending to give an intermediate hybrid). To distinguish between them an analogy can be helpful. Two co-school captains are equally expressed (= co-dominance), not incomplete or blended. Visual examples of red, white and roan cattle (co-dominance) and red, pink and white flowers (incomplete dominance) are helpful.
* The genetic notation for sex linked genes can be confusing for students. Practising Punnet squares will help redress this. Practice with pedigrees is often needed to allow students to confidently trace the inheritance of sex linked diseases.
* The concept of multiple alleles can be difficult for students to grasp. Students may try to make the number of alleles in the genotype equal the number of possible alleles. It is important that they understand that no matter how many possible alleles there are, an individual can only have two, with one inherited from each parent. Multiple alleles come with a cascade of dominance which can also cause problems. This can be likened to different hands in poker or tennis players being higher ranked than others. Again, practise with Punnett squares will develop this understanding.
* Understanding that single nucleotide polymorphisms can be genetic markers that are associated with specific traits but do not actually cause the trait, disease or disorder can be confusing for students. The role of non-coding regions (introns) of chromosomes is an area of ongoing research.
* Students will often confuse the processes of whole organism cloning and gene cloning. It is important that the teacher explicitly teaches the clear differences between these, using relevant examples.

## Suggested teaching strategies

This section will provide an overview of some suggested practical and secondary source investigations and resources that could be explored for each of the inquiry questions in these modules. There is no expectation that teachers need to teach these in any particular order; teachers are encouraged to link ideas across inquiry questions where they see fit.

### IQ 5-1: How does reproduction ensure the continuity of the species?

* Teachers could introduce the concept with the BBC video series [Nature’s Miracle Babies](https://www.bbc.co.uk/programmes/b014gsw7) which explores captive breeding programs. It is an engaging introduction to the need for successful reproduction for continuity of a species.
* A series of practical investigations could be conducted by collecting live plant specimens to observe asexual and sexual reproductive organs. Students could propagate some plants using various mechanisms, e.g. cuttings of geraniums or sweet potatoes, kikuyu rhizomes, onion bulbs, potato tubers. There is also an [Interactive Plant Virtual Dissection](https://www.cuhk.edu.hk/lifesciences/IVFDL/index.html) available online where students can participate in a dissection of three flowers.
* David Attenborough’s Private Life of Plants (includes fungi), Kingdom of Plants and Life of Mammals and The BBC Earth Channel show the various mechanisms of reproduction listed in the syllabus
* YouTube includes a range of relevant video series including:
	+ [The Science Show: Why Sex?](https://www.youtube.com/watch?v=gRpEt61XM4M) (duration 4:52). Explores why sex is the preferred method of reproduction for most species.
	+ [Amoeba Sisters: Plant Reproduction in Angiosperms](https://www.youtube.com/watch?v=HLYPm2idSTE) (duration 8:00). Compares and contrasts asexual reproduction with sexual reproduction. Worksheets available.
	+ TED ED – [The three different animals give birth](https://www.youtube.com/watch?v=sz3Yv3On4lE) (duration 4:49). Published on Apr 17, 2017. All mammals share certain characteristics, like warm blood and backbones. Despite their similarities, these creatures also have many biological differences — and one of the most remarkable differences is how they give birth. Includes a comparison of methods of giving birth in placental, marsupial and monotreme mammals.
	+ Nucleus Medical Media: [Ovulation](https://www.youtube.com/watch?v=wcVC3TFI7fQ) (duration 2:41) and [Fertilisation](https://www.youtube.com/watch?v=_5OvgQW6FG4) (duration 5:42) - short factual videos on with good animations.
* The manipulation of plant and animal production at this point refers to such processes as artificial pollination and tissue culture in plants and artificial insemination, synchronised oestrus, super ovulation and embryo transfer in animals. Teaching whole animal cloning and other genetic modification could be left to later in the modules.
* If teachers have access to an agricultural enterprise (wholesale nursery, farm) or a research facility (e.g. university, CSIRO) they could visit the establishment to observe technicians undertaking these processes in plants or animals. The emphasis is on how the development of scientific knowledge has allowed the development in the technology.

### IQ 5-2: How important is it for genetic material to be replicated exactly?

* The key messages in this inquiry question are that:
	+ The exact copying of the DNA sequence in mitosis ensures that the instructions carried in the DNA remain consistent for the life of the organism. A brief discussion about the role of enzymes in repairing errors in replication could be useful. This idea will be developed further in Module 8. Mutations in detail are considered at a later point.
	+ It is the variety of gametes produced by meiosis that give rise to variation in offspring which is necessary of species survival (this can relate back to Module 3).
* Model building is an integral part of this inquiry question. It is imperative for students to have a clear understanding of DNA structure in order to understand the remainder of this module. To activate prior learning of DNA structure from Stage 5 show the students a 3D model of DNA and determine if students can identify any components of DNA by labelling a diagram.
* Students could carry out secondary source research to determine the steps involved in DNA replication. Students could design a model to represent the process (e.g. using lollies, plasticine, K’Nex, pipe cleaners) in a practical investigation, then analyse the benefits and limitations of their model and its effectiveness.
* [Mitosis Mover](https://biomanbio.com/HTML5GamesandLabs/Genegames/mitosismoverpage.html), an interactive game by Biomanbio, could be used to explore the cell cycle and its role of in growth and repair.
* To investigate meiosis, the teacher could ask students to consider what would happen if the cells that were being produced by mitosis were sex cells and they combined to form a new individual. They will then see the need for the number of chromosomes to halve during production of gametes. Modelling of meiosis must demonstrate that while each gamete/sex cell contains one member of each homologous pair there is variety of sex cells that can be produced. This [sumanasinc animation](http://www.sumanasinc.com/webcontent/animations/content/meiosis.html) (duration 3:20) clearly and concisely shows the process of meiosis.
* There are a range of videos by McGraw-Hill Animations available that will assist in demonstrating concepts in this inquiry question including:
	+ Showing the structure of DNA in detail: Useful for more capable students to understand more advances aspects of DNA structure such as directionality, bond types and base-pairing.
	+ Replication animation showing the process of DNA replication and the enzymes involved.
	+ Mitosis in plant cells shows how the process of cytokinesis differs due to the presence of a cell wall.
	+ Comparison of meiosis and mitosis animation: A HD animation showing a comparison between mitosis and meiosis. Students could watch this and then construct a table or double bubble map to show the similarities and differences between the two processes.
* Crash Course Biology: DNA structure and replication is another video that provides excellent visual representation and explanation of the processes.

### IQ5-3: Why is polypeptide synthesis important?

* The structure and function of proteins can be explored in this [interactive program](https://learn.genetics.utah.edu/content/basics/proteintypes/) from learn.genetics.utah.edu. It will allow students to investigate the range proteins that exist in the human body, including those proteins are responsible for our structure, mobility, storage and transport of substances, metabolism and defence against disease. This will allow students to see that humans are far more genetically alike than we are different, as we all have the same proteins that make us a functioning human.
* Students can design and construct a model of transcription and translation, then assess their model. The model should include a promoter, terminator, introns and exons and a section of non-coding DNA outside of the gene. Alternatively, students can model using the simulation at the Genetic Science Learning Centre. Students view the videos in the Udacity course: Tales from the genome, and complete quizzes. This could be a useful formative assessment item. Use Chrome rather than Internet Explorer.
* McGraw-Hill Animations video on transcription and translation provides a more detailed look into polypeptide synthesis.
* Your Genome video also provides a clear 3D animation on polypeptide synthesis that is suitable for students of nearly all abilities.
* Having established that an individual’s cells all contain the same DNA with the genetic code to produce the same proteins, teachers could introduce the idea that in reality all cells do not look alike, they function differently, and do not all actually produce the same proteins. Transcription factors control what a cell will become. Gene expression is the switching on or off of genes determining whether a particular protein is produced. These concepts are explained well by [Garvan Institute of Medical Research](https://www.garvan.org.au/news-resources/genomics-explained).

### IQ 6-1: How does mutation introduce new alleles into a population?

* To activate prior learning the teacher could ask students to brainstorm ideas around the definition, causes and effects of mutations. This activity will allow the teacher to determine what conceptions are held by the students.
* A [3D animation](https://dnalc.cshl.edu/resources/3d/18-dna-damage.html) (duration 1:05) showing DNA being exposed to mutagens, such as free radicals and UV radiation, could be shown as an introduction to mutations.
* It is important to make the link between a mutation (from a single base pair to whole chromosomes) altering the genetic makeup of an organism to the potential change in protein synthesis. When describing point mutations, the analogy of substituting or deleting letters in a sequence of three letter words is a useful tool. For an example see appendix 2.
* [Mutation telephone activity](https://www.teachengineering.org/activities/view/uoh_mutations_lesson01_activity1): Students perform an activity in which each communication step represents a process of cell replication. This game illustrates how DNA mutations can happen over several cell generations and the effects the mutations can have on the proteins that cells need to produce. Instructions, worksheets and answers are all included.
* Students could make a model showing non-disjunction in meiosis as a cause of chromosomal mutation. A study of Down syndrome (or Klinefelter’s or Turner’s syndrome) ties in with content on non-infectious disease in Module 8.
* Distinguishing between somatic mutations and germ line mutations and their effects on an organism could be developed through students researching an example of each and then developing a table to compare and contrast them.
* Whilst changing a base sequence in coding DNA can be seen to directly affect protein synthesis, the effect of mutations on non-coding DNA, a new area in this syllabus, is a more complex process and an area of ongoing research. These mutations can affect gene expression, embryonic development and can be linked to both non-infectious and infectious disease. A teacher could summarise this [Non-coding mutations driving chronic lymphocytic leukaemia](https://ecancer.org/en/video/4711-non-coding-mutations-driving-chronic-lymphocytic-leukaemia) video (duration 13:40)
* Likewise, gene flow and gene drift are new content areas and it is important to provide clear definitions. Students can investigate the effect of [genetic drift](http://www.biology.arizona.edu/evolution/act/drift/drift.html) by undertaking an online simulation from the Biology Project at the University of Arizona. An online and a manual simulation is available. [Virtual Biology Lab](http://virtualbiologylab.org/population-genetics/) has several simulations. They have good visuals but are more complex than those above. [Simulating a genetic bottle neck](https://www.biologysimulations.com/genetic-drift-bottleneck-event) is an online simulation showing how genetic bottle necks increase genetic drift and affect the gene pool of populations.

### IQ 5-4: How can the genetic similarities and differences within and between species be compared?

* Many ideas in this inquiry question can be approached by modelling and problem solving. As an introduction to this inquiry question students could use this [make a karyotype](https://learn.genetics.utah.edu/content/basics/karyotype/) simulation.
* Modelling of crossing over and fertilisation will show how this process contributes to genetic variation. Modelling crossing over can be undertaken using coloured wool, plasticine or pipe cleaners to represent chromosomes. Students should assess the value of their model and explain how this contributes to genetic variation.
* To this point the processes involved in replicating cells and producing gametes have been relatively straightforward. Students may well have prior knowledge of using Punnett squares and pedigrees from Stage 5 however they should be given the opportunity to practise problems using simple autosomal inheritance to ensure that they are competent at this base level.
* Conduct a simple survey of dominant and recessive characteristics e.g. tongue rolling, free/attached earlobes, thumb position with clasped hands, length of second toe, etc. While assigning single gene pair inheritance to many of these characteristics is not strictly correct, for the purpose of the exercise it will show students that the dominant characteristic is not necessarily the most common. Students can then draw their own family tree, ascertain the phenotype of family members for one of these characteristics and assign genotypes where possible.
* Investigations into co-dominance, incomplete dominance, multiple alleles and sex linkage could include using online programs such as [The Blood typing game](https://educationalgames.nobelprize.org/educational/medicine/bloodtypinggame/), a Nobel Prize winning game to illustrate multiple alleles. The [Isihara Colour Test](https://www.color-blindness.com/ishihara-38-plates-cvd-test/) is one of many examples to determine colour blindness.
* A good resource for examining frequency data in populations is [Diving Adaptations in Sea Nomads](https://www.biointeractive.org/classroom-resources/diving-adaptations-sea-nomads). Data comparing the size of spleens in two populations is presented in a box and whisker plot. Students may not have seen this type of graph previously. A worksheet requiring students to analyse data is supplied.
* Analysing single nucleotide polymorphisms (SNPs) can be achieved by using the interactive lesson from Learn Genetics: [making SNPs make sense](https://learn.genetics.utah.edu/content/precision/snips/), explaining SNPs and how scientists locate SNPs in the genome. In the activity [Mapping Genes to Traits in Dogs Using SNPs](https://www.biointeractive.org/classroom-resources/mapping-genes-traits-dogs-using-snps), students identify SNPs that are correlated with different traits in dogs to identify genes associated with those traits.

### IQ 5-5: Can population genetic patterns be predicted with any accuracy?

* The majority of the content in this inquiry question is new. Teachers should ensure they read thoroughly to develop a sound understanding of the content and clarity about the depth required for students.
* Historically, the analysing of the patterns of inheritance of genetic traits in populations was very time-consuming. Bioinformatics brings together the fields of life science, computer science and statistics. The use of computers has increased the efficiency and speed and variety of applications available. The most recognised application of bioinformatics has been the mapping of the human genome sequence. A study of the development of the Human Genome Project is a good starting point for this inquiry question. [Human Genome Project](https://www.genome.gov/human-genome-project/What) is a website that gives an overview of the project and its impact.
* It is important that students have clear definitions of terms and the processes involved with DNA sequencing and profiling. This may be best delivered through direct instruction.
	+ DNA sequencing – determining the exact nucleotide sequence of a gene on a chromosome. A flow chart of the Sanger method is sufficient to investigate this technology
	+ DNA profiling – a technique used to compare individuals by characteristics of a small part of their DNA. Students will have some ideas of the use of this – paternity testing, forensics etc. A discussion around this will allow the dispelling of misconceptions. A short, clear animation outlining the processes involved in the polymerase chain reaction is the [McGraw-Hill PCR Animation](https://www.youtube.com/watch?v=NKw87DVrTH4). A flow chart will provide a clear visual of the processes involved.
* Having established the principles of DNA profiling students can investigate a paternity case or a crime by undertaking a first-hand gel electrophoresis. There are several suppliers of gel electrophoresis equipment and consumables. The equipment can be purchased at around $600 for a class or hired for a cost of $110 per kit. A kit will be sufficient for 6 student groups. Alternatively, a simulation of the process can be found at [Learn Genetics](https://learn.genetics.utah.edu/content/labs/gel/).
* To address the area of data analysis in population genetics for conservation management, determining the inheritance of a disease and human evolution, there are several suitable activities with appropriate data sets in the text books. Most online data sets are too complex for most Year 12 students however the following sites provide some accessible information and activities:
	+ The [Australian Museum’s Koala Genome](https://australianmuseum.net.au/get-involved/amri/the-koala-genome/) project can be used to investigate the use of population genetics in conservation management.
	+ [Genetic variation and human evolution resource:](https://education.nsw.gov.au/content/dam/main-education/teaching-and-learning/curriculum/key-learning-areas/science/s-6/biology/Genetic_variation_and_human_evolution_resource.pdf) This article provides good background information about the use of mitochondrial DNA and Y-chromosome DNA studies to determine a possible path for human evolution. Students could carry out their own research after reading this article.
	+ [Indigenous groups look to ancient DNA to bring their ancestors home.](https://www.nature.com/articles/d41586-019-01167-w) This nature.com article explores how local communities and geneticists are working together to sequence DNA from remains that were taken from their homelands decades ago.
* The depth study on the genetics of sickle cell anaemia and malaria resistance included in the appendix ties in this inquiry question and with Module 8.

### IQ 6-2: How do genetic technologies affect the Earth’s biodiversity?

### IQ 6-3: Does manipulation of DNA have the potential to change populations forever?

* Much of the vocabulary referred to in genetic technologies is new and needs to be used regularly and accurately to allow students to become confident in using the terms correctly.
* The technology involved in addressing these inquiry questions can be very complex. It is important that teachers explain each technology clearly before students undertake their own investigation into examples.
* These inquiry questions will generate many opportunities for class discussion. In order to make this constructive, have questions and scenarios prepared and have clear guidelines about students respecting others’ views.
* It is suggested that these inquiry questions could be taught by beginning with exploring ancient biotechnologies and the effect of these on the Earth’s biodiversity. The importance of biodiversity was demonstrated in 1845, during Ireland’s Great Famine. Only one type of potato, the Irish Limper, was the subsistence food for one-third of Ireland’s population. A plant pathogen, Phytophthora infestans, caused a widespread loss of the crops, resulting in famine and further poverty in the country. Over one million people died and nearly two million were forced to emigrate as a result. Students could be asked to explain why this occurred and assess the likelihood of an event like this happening in future. [Monoculture and the Irish Potato Famine: cases of missing genetic variation](https://evolution.berkeley.edu/evolibrary/article/agriculture_02) is an evolution.berkeley.edu article that explores the impact of lack of biodiversity.
* It is suggested teachers then move to the technologies that were introduced in the first inquiry question in Module 5 (selective breeding, artificial insemination, in vitro fertilization, embryo transfer and artificial pollination) and what their effect has been. While there is some control of the characteristics of the progeny/offspring with these technologies, it is not exact. There will still be genetic variation.
	+ [Breeding better salmon](https://www.csiro.au/en/research/animals/Aquaculture/breeding-salmon) by CSIRO investigates selective breeding in Tasmania's Atlantic salmon. It explores how the farming industry is improving the growth, health and product quality of salmon.
	+ [Artificial pollination of kiwi fruit](https://www.sciencelearn.org.nz/videos/19-artificial-pollination) (duration 2:44) explains the need for, and methodology of, artificial pollination.
* Students could conduct some practical investigations using biotechnology, e.g. making cheese, yogurt and artificially pollinating flowers. Instructions on how to [hand pollinate cucurbits](https://www.theseedcollection.com.au/blog/Hand-Pollinating-Curcurbits) (cucumbers, zucchini, pumpkin) may be useful.
* The study of modern genetic technologies could be started by investigating reproductive cloning. Students may be aware that cloning by embryo splitting is what occurs naturally with the production of identical twins. This process can be replicated in the laboratory and is practised widely in the cattle industry. Whole organism cloning by somatic cell nuclear transfer first came to the public’s attention in 1996 with the birth of Dolly. A flow chart showing the steps involved will make this process clear.
	+ [Whole organism cloning](https://learn.genetics.utah.edu/content/cloning/clickandclone/) simulation from Learn Genetics.
	+ The New York Times Retro Report: [The Story of Dolly the Cloned Sheep](https://www.youtube.com/watch?v=tELZEPcgKkE) (duration 13:39) from NYT outlining the implications of the first successful mammalian clone. Clear information about the cloning process and interesting discussion of the impacts of media and politics on scientific discoveries.
	+ [Cloning quiz](https://learn.genetics.utah.edu/content/cloning/cloningornot/) is a useful formative assessment item.
* Gene cloning could be introduced by exploring genetically modified organisms. Teachers could ask students to list some of the main problems that exist in the foods that they eat and then ask them how these might be solved, e.g. dripless tomatoes. Teachers could ask them to consider where the genes for these traits could potentially be sourced. This can lead into the genetic technologies where specific genes are identified, selected and inserted into offspring so that characteristics are tightly controlled. [What is Genetic Engineering? - Definition, Benefits & Issues](https://study.com/academy/lesson/what-is-genetic-engineering-definition-benefits-issues.html#lesson) (duration 8:32) clearly explains the purpose of genetic modification. The free portion of the video is 4mins 20s but this is sufficient. Here the class can discuss gene cloning as it is an integral part of the genetic modification process. The short video, [DNA cloning with plasmids](https://www.biointeractive.org/classroom-resources/dna-cloning-plasmids) (duration 1:12) shows the gene splicing process.
* Students need to be very clear that the genetic modification causes a change in the protein being synthesised. The example of the “spidergoat” where a large animal, the goat, is genetically modified for the express purpose of producing spider silk protein in its milk (rather than something that looks half goat/half spider) exemplifies this. [BBC: Horizon Playing God](https://www.bbc.co.uk/news/av/science-environment-16554357/the-goats-with-spider-genes-and-silk-in-their-milk) (duration 2:42) is a short video clip showing genetically modified goats. They have genes inserted that allow them to produce spider silk protein in their milk. This is the strongest naturally occurring substance known with potential for uses in the military.
* There is plethora of examples of the application and details of genetic technologies. It is often best to start with gene cloning and transgenics and their application in medicine (for example insulin production) and agriculture (such as Bt cotton). These are areas where there is plenty of clear information with flow charts showing the steps involved.
* [Breeding a sustainable future](https://www.primezone.edu.au/resources/YR10-BIOTECH.html) from the Primary Industries Education Foundation, is a unit of work on genetic modification in agriculture designed for Year 10, but sections of it will be useful for these inquiry questions. There are lessons, worksheets and links to a large number of websites.
* FAO: unbiased pdf [information](http://www.fao.org/3/i2490e/i2490e04d.pdf) and data regarding the world use of GM crops.
* [Biotechnology in Australia](https://www.agriculture.gov.au/ag-farm-food/biotechnology): a Department of Agriculture webpage with reports, articles, brochures and fact sheets examines the benefits of biotechnology and its potential contribution to innovation in the Australian agricultural sector. Includes a high-level snapshot of the department’s policy for biotechnology.
* This inquiry question lends itself to a secondary sourced investigation of genetic modification where the student can choose a GMO of interest, investigate the technology and discuss its potential benefits, ethical uses and social implications. Alternatively, a case study investigating the development, use and benefits of transgenic cotton can be undertaken to address several descriptors. Cotton has been continually selectively bred to maximise its production under the abiotic conditions in Australia and then there has been the genetic insertion of desirable traits. Current varieties have 5 genes inserted. The following are useful resources the specifically focus on cotton:
	+ [Biotechnology and Cotton](https://cottonaustralia.com.au/fact-sheet): Cotton Australia factsheet that provides a clear summary of the use, extent and benefits of biotechnology in the cotton industry.
	+ [Agricultural Biotechnology Council of Australia](http://www.abca.com.au/materials/resource-guides/): Webpage with links to GM cotton, GM carnations and GM canola.
	+ [Cotton Australia:](https://cottonaustralia.com.au/assets/general/Education-resources/CA-resources/Secondary/Research-case-study-A-Comparison-of-Arthropod-Communities-in-Transgenic-Bt-and-Conventional-Cotton-in-Australia.pdf) data on the biodiversity of arthropods in GM, Non-GM and sprayed cotton crops.
* When reading about healthy eating, the message is often to avoid those that are genetically modified (GM). Students can investigate why consumers have demanded “No GMO” labelling and evaluate its necessity. The following look at genetic modification of food crops:
	+ [Australian RNAi technology](https://www.csiro.au/en/research/production/biotechnology/RNAi): silencing gene expression for plant, animal and human health science. A new form of genetic modification.
	+ [CSIRO: Genetic modification:](https://www.csiro.au/en/research/production/biotechnology/Genetic-modification) A short fact sheet that lists the genetically modified crops that the CSIRO are developing and their potential benefits.
* There is an enormous amount of complex information available to help students to understand CRISPR-Cas9. The resources below are current and suitable for a high school student.
	+ [What is CRISPR-Cas9?](https://www.yourgenome.org/facts/what-is-crispr-cas9) clearly explains how CRISPR works.
	+ [A Scientific Discovery That Makes Genetic Engineering Safer To Use](https://www.forbes.com/sites/kevinmurnane/2017/01/03/a-scientific-discovery-that-makes-genetic-engineering-safer-to-use/#655f06477e75). This Forbes article has videos embedded and discusses problems and improvements with CRISPR.
* The following resources explore the future directions of biotechnology:
	+ [BIO](https://archive.bio.org/bio-areas-focus) is the world's largest trade association representing biotechnology companies, academic institutions, state biotechnology centres and related organizations across the United States and in more than 30 other nations. BIO members are involved in the research and development of innovative healthcare, agricultural, industrial and environmental biotechnology products. Useful for investigating the uses and applications of biotechnology, particularly future directions and potential benefits.
	+ [TED Talk: 5 challenges we could solve by designing new proteins](https://www.ted.com/talks/david_baker_5_challenges_we_could_solve_by_designing_new_proteins) (duration 10:20) explores the cutting edge innovations for future use of biotechnology.
	+ [CSIRO: Next generation cotton](https://www.csiro.au/en/research/production/materials/Next-gen-cotton) – a short fact sheet and video that looks at the where plant breeding is heading with cotton.
* This will lead naturally into a discussion of the social and ethical implication of the uses of biotechnology. Gene testing and gene editing of human embryos and adults can be included here. A class debate, after viewing a range of resources and using evidence, reasoning and the basic principles of ethics, will allow for a range of scenarios and views to be presented.
* [HHMI Central Dogma and Genetic Medicine.](https://www.biointeractive.org/classroom-resources/central-dogma-and-genetic-medicine) This interactive module uses the central dogma as a model for exploring how modern molecular biology technologies can be used to treat different genetic conditions including cystic fibrosis, sickle cell disease, and Huntington’s disease – a future direction of the use of biotechnologies.
* [CRISPR editing of plants and animals gets green light in Australia.](https://www.abc.net.au/news/science/2019-04-30/crispr-gene-editing-in-the-food-chain/11053622)  Stimulus material for class debate around Bioethics.
* [Science Journal for Teens:](https://sciencejournalforkids.org/articles/how-can-gene-editing-cure-disease/) Scientists wanted to use genetic editing to heal β-thalassemia - a genetic disease affecting the body's ability to produce haemoglobin. Cutting edge, peer-reviewed, science research adapted for students.
* SBS Insight: Panel and audience discussion:
	+ [In your genes part 1](https://www.sbs.com.au/news/insight/tvepisode/in-your-genes) (duration 16:41) and [Part 2](https://www.sbs.com.au/ondemand/video/11736131584/in-your-genes-part-2) (duration 23:32): Would you want to know about carrying a gene that killed you? Looks at gene testing.
	+ [Designing babies:](https://www.sbs.com.au/ondemand/video/11862083517/insight-designing-babies) (duration 51.50) Should humans embrace the new genetic technologies to ‘breed out’ disease and illness, whether it is wrong to play God and interfere with nature and where do we draw the line?

## Resources

### General resources

* [DNA learning centre](https://www.dnalc.org/resources/3d/18-dna-damage.html) has a variety of high-quality resources and animations. The 3D Animation Library has good “real time” animations showing replication, transcription, translation, splicing and as it would occur in real time.
* [HHMI Biointeractive](https://www.biointeractive.org/home). Award-winning multimedia resources, including apps, animations, videos, interactives, and virtual lab. Video resources are supplemented by teacher guides and classroom activities.
* [The Genetic Science Learning Centre in UTAH](https://learn.genetics.utah.edu/content/basics/proteintypes/) has a variety of high quality activities for students including an online simulation for building a DNA molecule.

### IQ 5-1:

* [Nature’s Miracle Babies](https://www.bbc.co.uk/programmes/b014gsw7). A BBC video series about captive breeding programs for threatened species. A good introduction to the need for successful reproduction for species survival.
* [Interactive virtual plant dissection lab](https://www.cuhk.edu.hk/lifesciences/IVFDL/): A plant dissection is demonstrated, a glossary of terms included and students can virtually dissect three flowers and answer questions.
* [The Science Show: Why Sex](https://www.youtube.com/watch?v=gRpEt61XM4M) (duration 4:52). A video that explores why sex is the preferred method of reproduction for most species.
* [Amoeba Sisters: Plant Reproduction](https://www.youtube.com/watch?v=HLYPm2idSTE) (duration8:00), compares and contrasts asexual reproduction with sexual reproduction. Worksheets available.
* [TED ED – The three different animals give birth](https://www.youtube.com/watch?v=sz3Yv3On4lE) (duration4:49), published on Apr 17 2017. All mammals share certain characteristics, like warm blood and backbones. Despite their similarities, these creatures also have many biological differences — and one of the most remarkable differences is how they give birth. Includes a comparison of methods of giving birth in placental, marsupial and monotreme mammals.
* [Ovulation](https://www.youtube.com/watch?v=wcVC3TFI7fQ) (duration 2:41) and [Fertilisation](https://www.youtube.com/watch?v=_5OvgQW6FG4) (duration 5:42) from Nucleus Medical Media - short factual videos with good animations.

### IQ 5-2

* [Mitosis mover:](https://biomanbio.com/HTML5GamesandLabs/Genegames/mitosismoverpage.html) an interactive game by Biomanbio. This covers the cell cycle, interphase, mitosis, cytokinesis, chromatin, chromosomes and the role of the cell cycle in growth and healing. This is a short interactive useful for helping students understand the basics of the cell cycle and how one cell divides to form two genetically identical daughter cells.
* [Meiosis](http://www.sumanasinc.com/webcontent/animations/content/meiosis.html) animated tutorial examines the events of meiosis using model cell with two pairs of chromosomes. A quiz is also included. A list of other tutorials is provided on the home page.
* McGraw-Hill Biology and Crash Course Biology (Video#10) have high quality YouTube videos and animations of DNA structure, mitosis and meiosis

### IQ 5-3

* [Types of Proteins](https://learn.genetics.utah.edu/content/basics/proteintypes/) from Learn Genetics. Web pages with images and information about each type of protein.
* [Transcribe and Translate a Gene](https://learngendev.azurewebsites.net/content/basics/txtl/) : a video and interactive from Learn Genetics (use Chrome)
* McGraw Hill: Transcription and Translation YouTube video
* From DNA to Protein: This 3D animation from Your Genome on YouTube shows how proteins are made in the cell from the information in the DNA code.

### IQ 6-1

* [DNA damage](https://dnalc.cshl.edu/resources/3d/18-dna-damage.html), a 3D animation from the DNA Learning Centre, shows DNA being exposed to mutagens such as free radicals and UV radiation. This could be shown as an introduction to mutations.
* [Mutation telephone](https://www.teachengineering.org/activities/view/uoh_mutations_lesson01_activity1): Students perform an activity similar to the childhood “telephone” game in which each communication step represents a biological process related to the passage of DNA from one cell to another. This game tangibly illustrates how DNA mutations can happen over several cell generations and the effects the mutations can have on the proteins that cells need to produce. Next, students use the results from the “telephone” game (normal, substitution, deletion or insertion) to test how the mutation affects the survivability of an organism in the wild. Instructions, worksheets and answers are all included.
* [Non coding mutations driving chronic lymphocytic leukaemia](https://ecancer.org/en/video/4711-non-coding-mutations-driving-chronic-lymphocytic-leukaemia) explains how mutations in non-coding regions can be linked to non-infectious disease in significant detail – suited for teacher reference.
* [Genetic Drift Simulation:](http://www.biology.arizona.edu/evolution/act/drift/drift.html) In this activity students visualize evolution at a simple level and develop their understanding of genetic drift. The teacher’s notes page has printable student worksheets and classroom planning information.
* [Virtual Biology Lab](http://virtualbiologylab.org/population-genetics/) has several population genetics models that are excellent but more complex than that above.
* [Simulating a genetic bottle neck](http://archive.pov.org/sunkissed/lesson-plan/) is an online simulation about a real incidence of a genetic disorder in the Navajo population, showing how genetic bottle necks increase genetic drift and affect the gene pool of populations.

### IQ 5-4

* [Make a Karyotype](https://learn.genetics.utah.edu/content/basics/karyotype/) is an interactive from Learn Genetics where students sort a collection of chromosomes into a karyotype
* [The Blood Typing Game](https://educationalgames.nobelprize.org/educational/medicine/bloodtypinggame/) is a Nobel Prize winning game. Students see what happens if you get a blood transfusion with the wrong blood type. Even though a patient's own blood type is the first choice for blood transfusions, it's not always available at the blood bank. Students try to save some patients' lives and learn about human blood types. An excellent interactive demonstrating multiple alleles.
* The [Isihara Colour Test](https://www.color-blindness.com/ishihara-38-plates-cvd-test/) is an online colour blind test.
* [Diving adaptations in Sea Nomads](https://www.biointeractive.org/classroom-resources/diving-adaptations-sea-nomads), from BioInteractive, examines gene frequency in a population. Data comparing the size of spleens in two populations is presented in a box and whisker plot. Students may not have seen this type of graph previously, so this provides an opportunity for students to be introduced to this type of data representation. A teacher guide and worksheet requiring students to analyse data is supplied. To introduce these people there are multiple videos of varying lengths available by doing a Google search on Sea Nomads.
* [Making SNPs make sense](https://learn.genetics.utah.edu/content/precision/snips/), from Learn Genetics, is an interactive lesson where single nucleotide polymorphisms and their role in the effectiveness of therapeutic drugs are explained.
* [Mapping Genes to Traits in Dogs Using SNPs](https://www.biointeractive.org/classroom-resources/mapping-genes-traits-dogs-using-snps), from BioInteractive, is an activity where students identify single nucleotide polymorphisms (SNPs) that are correlated with different traits in dogs to identify genes associated with those traits. Teacher directions and student worksheets are provided.

### IQ 5-5

* [Human Genome Project](https://www.genome.gov/human-genome-project/What) is a website that gives an overview of the project and its impact.
* [Gel electrophoresis](https://learn.genetics.utah.edu/content/labs/gel/) virtual lab from Learn Genetics is an alternative to running a live gel.
* [The Australian Museum’s Koala Genome project](https://australianmuseum.net.au/get-involved/amri/the-koala-genome/) can be used to investigate the use of population genetics in conservation management.
* [Genetic variation and human evolution resource](https://education.nsw.gov.au/content/dam/main-education/teaching-and-learning/curriculum/key-learning-areas/science/s-6/biology/Genetic_variation_and_human_evolution_resource.pdf) is an article that provides good background information about the use of mitochondrial DNA and Y-chromosome DNA studies to determine a possible path for human evolution. Students could carry out their own research after reading this article.
* [Indigenous groups look to ancient DNA to bring their ancestors home:](https://www.nature.com/articles/d41586-019-01167-w) an article that explores how local Indigenous communities and geneticists are working together to sequence DNA from remains that were taken from their homelands decades ago.

### IQ 6-2 and 6-3

#### Traditional biotechnology

* [The Irish Potato Famine](https://evolution.berkeley.edu/evolibrary/article/agriculture_02) is an article that explores the impact of lack of biodiversity.
* [Breeding better salmon](https://www.csiro.au/en/research/animals/Aquaculture/breeding-salmon): CSIRO are working with Tasmania’s Atlantic salmon industry using selective breeding to improve the growth, health and product quality of farmed salmon. A short web page of information.
* [Artificial pollination of kiwi fruit](https://www.sciencelearn.org.nz/videos/19-artificial-pollination) is a short [video](https://www.sciencelearn.org.nz/videos/19-artificial-pollination) (duration 2:44) explaining the need for, and methodology of, artificial pollination.
* [Hand pollinating cucurbits](https://www.theseedcollection.com.au/blog/Hand-Pollinating-Curcurbits) has instructions to hand pollinate cucurbits (cucumbers, zucchini, pumpkin).

#### Whole organism cloning

* [Whole organism cloning](https://learn.genetics.utah.edu/content/cloning/clickandclone/) from Learn Genetics is an interactive where students ‘clone’ a mouse.
* [The Story of Dolly the Cloned Sheep](https://www.youtube.com/watch?v=tELZEPcgKkE) (duration 13:39) is from the New York Times outlining the implications of the first successful mammalian clone. Clear information about the cloning process and interesting discussion of the impacts of media and politics on scientific discoveries.
* [Cloning quiz](https://learn.genetics.utah.edu/content/cloning/cloningornot/) is a useful formative assessment item.

#### Gene cloning and transgenic organisms

* [What is Genetic Engineering? - Definition, Benefits & Issues](https://study.com/academy/lesson/what-is-genetic-engineering-definition-benefits-issues.html#lesson) (duration 8:34) is from Study.com. The free portion of the video clearly explains the purpose of genetic modification and the role of gene cloning.
* [The goats with spider genes and silk in their milk](https://www.bbc.com/news/av/science-environment-16554357/the-goats-with-spider-genes-and-silk-in-their-milk) (duration 2:42) a BBC Horizon video showing genetically modified goats. Useful for showing that GM organisms may look no different to the regular organism.
* [Breeding a sustainable future](https://www.primezone.edu.au/resources/YR10-BIOTECH.html) from the Primary Industries Education Foundation is a unit of work on genetic modification in agriculture designed for Year 10, but sections of it will be useful for these inquiry questions. There are lessons, worksheets and links to a large number of websites.
* [Genetically Modified Crops](http://www.fao.org/3/i2490e/i2490e04d.pdf): a pdf web page from the Food and Agriculture Organisation providing information and data regarding the world use of GM crops.
* [Biotechnology in Australia](https://www.agriculture.gov.au/ag-farm-food/biotechnology): Department of Agriculture webpage with reports, articles, brochures and fact sheets examining the benefits of biotechnology and its potential contribution to innovation in the Australian agricultural sector. Includes a high-level snapshot of the department’s policy for biotechnology.

#### GM Cotton

* [Biotechnology and Cotton:](https://cottonaustralia.com.au/fact-sheet) Webpage that provides a clear summary of the use, extent and benefits of biotechnology in the cotton industry.
* [Resource Guides](http://www.abca.com.au/materials/resource-guides/) is a web page of the Agricultural Biotechnology Council of Australia with links to GM cotton, GM carnations and GM canola.
* [Cotton Australia](https://cottonaustralia.com.au/assets/general/Education-resources/CA-resources/Secondary/Research-case-study-A-Comparison-of-Arthropod-Communities-in-Transgenic-Bt-and-Conventional-Cotton-in-Australia.pdf): A lengthy report that could provide useful data on the biodiversity of arthropods in GM, Non-GM and sprayed cotton crops for a depth study.

#### GM Food

* [Silencing genes with RNAi](https://www.csiro.au/en/Research/Farming-food/Innovation-and-technology-for-the-future/Gene-technology/RNAi) A new form of genetic modification for plant, animal and human health science developed by the CSIRO.
* [Genetic modification](https://www.csiro.au/en/research/production/biotechnology/Genetic-modification): A short fact sheet from the CSIRO that lists the genetically modified crops that the CSIRO are developing and their potential benefits.

#### CRISPR-Cas9

* [What is CRISPR-Cas9](https://www.yourgenome.org/facts/what-is-crispr-cas9)? This webpage clearly explains how CRISPR works.
* [A Scientific Discovery That Makes Genetic Engineering Safer To Use](https://www.forbes.com/sites/kevinmurnane/2017/01/03/a-scientific-discovery-that-makes-genetic-engineering-safer-to-use/#655f06477e75): a webpage with videos that discusses the problems and improvements with CRISPR.

#### Future directions of Biotechnology

* [BIO](https://www.bio.org/) the website of the Biotechnology Association: useful for investigating future directions and potential benefits of biotechnology
* TED Talk: [5 challenges we could solve be designing new proteins](https://www.ted.com/talks/david_baker_5_challenges_we_could_solve_by_designing_new_proteins?language=en) (duration 10:20). This video explores the cutting-edge innovations for future use of biotechnology.
* [Next generation cotton](https://www.csiro.au/en/research/production/materials/Next-gen-cotton) – a short fact sheet and video from the CSIRO that looks at the future directions of cotton breeding.

#### Social and ethical implications

* Medicine. This interactive module uses the central dogma as a model for exploring how modern molecular biology technologies can be used to treat different genetic conditions including cystic fibrosis, sickle cell disease, and Huntington’s disease – a future direction of the use of biotechnologies.
* [CRISPR editing of plants and animals gets green light in Australia](https://www.abc.net.au/news/science/2019-04-30/crispr-gene-editing-in-the-food-chain/11053622). An ABC article that looks at the legislation surrounding the use of CRISPR. Updated regulations allow scientists to use some genome-editing techniques in plants and animals without government approval.
* [How can gene editing cure disease?](https://sciencejournalforkids.org/articles/how-can-gene-editing-cure-disease/) Scientists wanted to use genetic editing to heal β-thalassemia - a genetic disease affecting the body's ability to produce haemoglobin. Cutting edge, peer-reviewed, science research, adapted for students.
* [In your genes part 1](https://www.sbs.com.au/news/insight/tvepisode/in-your-genes) (duration 16:41) and [Part 2](https://www.sbs.com.au/ondemand/video/11736131584/in-your-genes-part-2) (duration 23:32): Would you want to know about carrying a gene that killed you? Looks at gene testing.
* [Designing babies:](https://www.sbs.com.au/ondemand/video/11862083517/insight-designing-babies) (duration 51.50) should humans embrace the new genetic technologies to ‘breed out’ disease and illness, whether it is wrong to play God and interfere with nature and where do we draw the line?

## Appendix 1

An activity to introduce transcription and translation

Provide students with the following stimulus:

You have been asked to do a PowerPoint presentation on lions. Imagine you are in pre-internet days and would like to use the encyclopaedias found in the library as a source of information. The librarian is very protective of the encyclopaedias and does not allow them to leave the library, but you would like to do the assignment at home. How do you overcome this problem?

Have students brainstorm in groups ideas. Relate to the concept of DNA ‘locked’ inside the nucleus. Relate photocopying certain pages of the encyclopaedia to the idea of transcribing certain genes. You take those pages out of the library (nucleus) home to your computer (ribosome) where you can convert that photocopy (mRNA) into a presentation (polypeptide).

## Appendix 2

An analogy for introducing point mutations.

Consider the following series of letters (even though they are not bases)

THEBIGCATATETHERAT

If we look at this in groups of three it reads:

THE BIG CAT ATE THE RAT

If a single letter is substituted, for example F for R, the sentence is slightly changed

THE BIG CAT ATE THE FAT

However, if a single letter is deleted, for example the C, this changes the sequence so the sentence is entirely meaningless

THE BIG ATA TET HER AT

Consequently, a base deletion most likely will have a more significant effect than a base substitution on the capacity of the gene to produce a functional protein.