Genetics

Unit 3

This unit should fill approximately **26 periods** of teaching time.

Learning competencies for Unit 3

By the end of this unit students should be able to:

- Work out the outcomes of monohybrid crosses and dihybrid crosses.
- Use the Punnett square to determine genetic crosses.
- Determine genotypes and phenotypes formed in a genetic cross.
- Explain the different types of dominance.
- Describe the significance of the fact that not all genes show a straightforward dominant/recessive relationship between different alleles of the gene.
- State that some genes have more than two alleles.
- Describe the different stages of meiotic division.
- Describe the significance of meiosis as both a source of variation through crossing over and independent assortment as well as a method of halving chromosome number in the gametes.
- Describe how a knowledge of genetics is important in artificially producing new varieties of crops and stock animals through artificial cross-breeding and inbreeding.
- Explain why fruit flies (*Drosophila melanogaster*) have been used in much genetic research.
- Explain the genetic basis of gender determination and why it is that some characteristics are sex-linked, sex-influenced or sex-limited.
- Describe the structure of a chromosome.
- Describe in detail the structure of the DNA molecule.
- Name the four nucleotides that build up the DNA molecule.
- Construct a model of DNA showing the base pair between complementary nucleotides.
- Describe the semi-conservative replication of DNA.
- Describe the significance of some of the uses of gene technology in forensic science (such as genetic fingerprinting).
- Describe how genetic fingerprints are produced.
- Define and give examples of cloning.
- Understand that genes can be cloned and explain in outline how this is achieved.
- Describe, in outline, the procedures involved in genetic engineering and appreciate that whilst there are many advantages that result from the process, there are also some ethical concerns about some of the procedures.
- Describe how the flow of information in a cell starts from the code on DNA and ends with proteins being synthesised.
- Understand the nature of the genetic code.

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- Describe the roles of DNA, mRNA, tRNA and ribosomes in protein synthesis and understand the processes of transcription, translation and gene expression.
- Understand that protein synthesis depends on having a supply of amino acids which, in animals, come from the food they eat.
- Understand the different roles proteins have in cells and in the body.
- Explain what is meant by the term mutation.
- Describe some of the different types of mutations.
- Describe and explain some of the causes of mutations.
- State the spontaneity of a mutation.
- Describe and explain some of the consequences of mutations.
- Give examples of inheritable mutations.

3.1 Genetic crosses

This section should fill approximately **10 periods** of teaching time.

Learning competencies

By the end of this section students should be able to:

- Work out the outcomes of monohybrid crosses and dihybrid crosses.
- Use the Punnett square to determine genetic crosses.
- Determine genotypes and phenotypes formed in a genetic cross.
- Explain the different types of dominance.
- Describe the significance of the fact that not all genes show a straightforward dominant/recessive relationship between different alleles of the gene.
- State that some genes have more than two alleles.
- Describe the different stages of meiotic division.
- Describe the significance meiosis as both a source of variation through crossing over and independent assortment as well as a method of halving chromosome number in the gametes.
- Describe how a knowledge of genetics is important in artificially producing new varieties of crops and stock animals through artificial cross-breeding and inbreeding.
- Explain why fruit flies (*Drosophila melanogaster*) have been used in much genetic research.
- Explain the genetic basis of gender determination and why it is that some characteristics are sex-linked, sex-influenced or sex-limited.

Starting off

This unit involves three main themes:

- Classical Mendelian genetics.
- Molecular genetics.
- Meiosis and gamete formation.

It is as well at the outset to establish a link between the actual genes that will be discussed in genetic crosses and their location on chromosomes and the fact that each gene is a section of a DNA molecule.

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Students will also need either to be reminded of the meaning of the following terms, or in some cases to have them explained for the first time.

- gene
- allele
- genotype
- phenotype
- homozygous
- heterozygous
- dominant
- recessive
- gene locus

They are essential to the concepts that will be developed later in the unit.

Teaching notes

Students will not have studied genetics since grade 10, and so a revision of Mendel's work is appropriate and students should appreciate the precise methodology used in his breeding experiments and the reasons for his reciprocal crosses.

They should appreciate the need for using pure-breeding parents and should be able to notice a general pattern from parental generation through to F2 in all his crosses and that it was this general pattern, rather than results from one specific cross, that allowed Mendel to arrive at his conclusions about the way in which traits were inherited and to formulate his laws of inheritance.

The work so far should be, largely, a revision of their work in grade 10. They should know how to represent monohybrid crosses from this work. But at grade 12 they should be able to make deductions from information given. They should be able to work out that if two parents showing the same trait produce offspring showing the alternative version of a trait, that the two parents must be heterozygous and that this also allows us to deduce which of a pair of alleles is dominant. In the situation described, the heterozygous parents must be displaying the trait determined by the dominant allele. So, to decide which allele is dominant they should look for information where two parents showing one version of a trait produce offspring showing the alternate version. This is illustrated in the Students' Book by reference to genetic pedigrees of widow's peak and albinism. Other examples of pedigrees are useful to give students practice at determining which is dominant and which recessive and then determining genotypes from this starting point.

Some sample pedigrees can be obtained from:
www.svusd.k12.ca.us
www.teachers.henrico.k12.va.us

We now move on to considering dihybrid inheritance and students must appreciate here the law of independent assortment. The alleles of one gene are inherited completely independently of the alleles of another gene. This is illustrated in figures 3.12 and 3.13 in the Students' Book. Both these figures need careful study and explanation, but once the students examine the principle, they will find no problem with dihybrid inheritance showing no linkage.

Practice problems in dihybrid inheritance can be found at:

www.biology.arizona.edu

The concept of codominance is introduced next, and this is usually accepted by students quite easily. It is just a matter of suggesting 'What if …' about the idea of dominant/recessive and giving an example. This is quite straightforward and should require little discussion beyond that which is given in the Students' Book.

The concept of multiple allele inheritance is a little trickier. The stumbling block, which therefore needs addressing at the outset, is that some students miss the points that:

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- There are more than two alleles of a gene in the population as a whole.
- Any individual still possesses only two alleles of the gene.

A revision of the introductory section on genes and chromosomes, with particular reference to homologous pairs of chromosomes, should help to drive the point home.

The inheritance of the ABO blood groups provides a convenient example as it continues the theme of codominance just discussed.

Next the physical basis of inheritance is considered. There are three important ideas to get across to the students at the beginning of this section:

- Genes are carried on chromosomes.
- The only physical link between the generations is the sex cells.
- The sex cells are formed by meiosis.

So, we should expect to find behaviour of chromosomes in meiosis that mirrors the behaviour of the genes we have so far discussed.

Students do not find meiosis an easy topic to appreciate, and it must be approached in stages. The books suggests an approach in three stages:

1. The key outcomes of meiosis – four daughter cells, a haploid number of chromosomes and genetic variation.
2. An overview of the behaviour of just one pair of chromosomes throughout the process to give an understanding of:
   - bivalent formation and crossing over in prophase I
   - the separation of homologous chromosomes at anaphase I
   - the separation of chromatids at anaphase II.
3. A detailed description of all the stages of meiosis. The students often find this very difficult to retain and they should be reassured that the really important issue is that they appreciate the key features and can state the two ways in which variation in the daughter cells is achieved.

Having considered the physical basis of inheritance, the concept of linked genes is more readily accepted by students. Clearly, if chromosomes are the physical means by which genes are passed from one generation to the next, then as each chromosome carries many genes there must be some genes that cannot be subject to independent assortment.

Students should appreciate that linked genes behave as a single unit and therefore the ratios that we predict are the same as when we are considering a single gene – they are the ratios of monohybrid inheritance.

The next concept – that of crossing over and recombinant types – is a difficult one for students to grasp as it depends on a thorough appreciation of meiosis. A revision of the overview of meiosis, particularly of crossing over, is recommended before progressing to discuss recombinant types.

Ask the students the following questions in the context of a single pair of homologous chromosomes:

- What happens during crossing over?
- What would happen if the one of the chromosomes that make up the bivalent carried both dominant alleles of two genes while the other carried both recessive alleles of the two genes.
- What will be the genotypes of the four gametes that will be produced?

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After this, they should see that if crossing over does occur, then linked genes can be separated and combinations that would not normally be expected can arise.

Finally, ask the students whether crossing over is more likely to occur between two genes if they are nearby on a chromosome or if they are more distantly spaced. An understanding of this can lead into a discussion of cross over values and the way in which they can be used to map genes on chromosomes.

This can be linked to the work of Morgan and Sturtevant with fruit flies and a discussion of why fruit flies make ideal organisms for genetic experimentation.

The use of a knowledge of genetics in plant and animal breeding has already been introduced in grade 10 when considering the principles of selective breeding. However, at this level we want the students to appreciate some of the genetic outcomes that lead to desirable types being the result of breeding practices.

Students should appreciate that cross-breeding two different varieties of a species will result in a hybrid that combines many of the dominant alleles from the two different varieties, but in heterozygous form. Since dominant alleles are often associated with the increased productivity, the hybrid usually shows more vigour than either of the original varieties. Several examples are provided in the Students' Book and some data are also given for analysis.

Students should also appreciate that inbreeding over many generations is a method employed to produce pure lines – as Mendel had already found out.

Sex determination has already been dealt with at the chromosomal level in grade 10. Now it is appropriate for students to appreciate just how the Y chromosome is able to exert its influence. The actual genetics is, in essence, quite simple. Although other genes besides the SRY gene are involved, it is essentially the action of this one gene that determines the way in which the urogenital ridge develops. From this, a brief discussion of abnormal sex genotypes can follow.

It is also valuable that the students appreciate that gender is not always determined in the same way and other genetic methods of gender determination can be discussed as well as some in which gender is environmentally determined. Examples are given in the Students' Book.

Sex-linked genes are usually quite readily accepted by the students; the X and Y are chromosomes and so must carry genes just as other chromosomes do. Because of the difference in the X and Y chromosomes in males and females, genes on these chromosomes will be inherited differently.

Most of the focus is on traits determined by recessive alleles that are carried on the X chromosome, such as red–green colour blindness. Get students to think about the likely pattern of inheritance of such traits before presenting them with any data. They should be able to predict:

- An increased chance of males inheriting these traits.
- Females act as 'carriers'.
- The condition may skip a generation.

With this established, it would be appropriate for students to look at several pedigrees of sex-linked features and try to work out genotypes of specific individuals.

The final concepts of this section, those of sex-influenced and sex-limited traits are usually quite readily understood when the examples are given.

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SA = starter activity MA = main activity CA = concluding activity	
What is the relationship between chromosomes, genes, alleles and characteristics?	
SA	Much of what is covered in this lesson is not new, but it all needs putting together to form the whole picture. Students revise with the teacher from their work in grade 11: • the structure of a chromosome • the relationship between DNA and genes.
MA	Introduce the students to the terms in the key words box on page 104. Then get the Students make a diagram (either as a display or in their notes) to show: • a pair of homologous chromosomes comprising two chromatids • the loci of at least two genes one of which has different alleles on each chromosome and the other with the same allele on each chromosome (the alleles will be the same on the two chromatids of each chromosome). They need to label the diagram using all the following terms: chromosome, chromatid, gene, allele, locus, homozygous, heterozygous.
CA	Class to review the terms.
How do we predict ratios in a monohybrid cross?	
SA	Students examine the meaning of the term monohybrid cross. They will be familiar with the cross, but perhaps not with the name.
MA	Students review Mendel's technique and results and the concepts of dominant and recessive alleles. Students discuss figure 3.6 with the teacher and make sure they understand why there is a 3:1 ratio. Then, set them a similar problem to work out. Perhaps a cross between tall and dwarf parents. Use the symbols T and t for the alleles, so the two parents would be TT and tt.
CA	Students try the problems listed under 'See if you can solve the following' (page 108).
How can parents showing one version of a feature have children with the other version?	
SA	This is a key lesson since it underpins much of the logic that will enable Students solve genetic problems.
MA	Using the example of the attached earlobe situation, students need to appreciate the following logic: • the alleles for any trait shown by children can only be inherited from their parents (this seems so obvious, but it is really worth pressing it home) • if children show a different version of a feature to their parents, then the allele that determines it must have come from their parents • this means the parents must have two alleles – the one they show and the different one that has been passed on to the children • so the parents are heterozygous and the feature that they show is determined by the dominant allele; the different feature shown by the children is determined by the recessive allele. Students carry out the seed counting activity, 3.4. Split students into pairs or groups and explain to them that the allele for purple seeds is dominant to that for yellow seeds and that a cob with seeds of both colours is the result of cross-breeding two plants that are heterozygous for purple seeds. Now ask them to look at the picture (or distribute real corn cobs if available), count the seeds and comment on whether the ratio of yellow to purple is what they expected.

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CA	Students carry out activity 3.3, to see how predictions match reality. Depending on what materials you have available they can either make individual spinners, one per group, or the teacher can make one for the whole class. A spinner like the one pictured on page 109 of the textbook can easily be made using coloured paper, scissors and a pin - alternatively there is a printable template students could adapt here: http://jc-schools.net/tutorials/gameboard.htm <http://jc-schools.net/tutorials/gameboard.htm>. Ensure students follow the instructions in the textbook and record their results accurately.
How could you find out if an organism showing the trait determined by a dominant allele is homozygous or heterozygous?	
SA	Students examine that individuals homozygous for the dominant allele and heterozygotes will appear identical. Through question and answer get the Students deduce that the only way of distinguishing them is by a genetic cross.
MA	Students discuss the possible genotypes of the organisms and understand that to determine which of the two it is: • we need to be able to predict possible outcomes of the cross • to do this, we need to know the genotype of the organism we will use to breed the unknowns with • this can only be an organism that is homozygous for the recessive allele Students discuss the possible outcomes.
CA	Set the students some other problems to produce test crosses.
How can we decide whether an allele is dominant or recessive?	
SA	Introduce the idea of representing genetic information as a pedigree.
MA	Activity 3.5 will reinforce these principles. The teacher should explain carefully to students what a family tree is and that each level represents a new generation of the family: talk through the questions in class before students work through them in groups and discuss their answers at the end.
CA	Class to review the principle of establishing which allele is dominant.
What are the patterns in dihybrid inheritance?	
SA	Review the law of independent assortment.
MA	Students discuss a dihybrid cross with the teacher, stressing the independent assortment of alleles in gamete formation. Once the all the stages have been discussed, get the Students analyse the F2 Punnett square and count up: • the numbers of round and wrinkled individuals • the numbers of yellow and green individuals. They should find that nothing has changed – the individual features are still in the ratio 3:1. Class to review the test cross for monohybrid crosses and Students predict what the test cross for a dihybrid cross will be.
CA	Students practise problems on dihybrid inheritance.
Codominance and multiple allele inheritance	
SA	Introduce the ideas that: • alleles are not always simply dominant or recessive • there are sometimes more than two alleles per feature.
MA	Students study flower colour in snapdragons to understand simple codominance. Students study the inheritance of ABO blood groups to understand codominance with multiple allele inheritance.
CA	Students work out some problems based on multiple allele inheritance and codominance.

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What is the physical basis for these patterns of inheritance?	
SA	Question and answer to re-establish that the physical link between generations is the chromosomes in the sex cells and that behaviour of these in gamete formation must mirror the behaviour of alleles.
MA	Students recall meiosis and the key features of the process: • two nuclear divisions • producing four daughter cells • producing haploid daughter cells • producing daughter cells showing genetic variation. Students discuss the overview of meiosis in figure 3.17 before going into any details of the process. If microscope slides of anthers or similar are available, students could examine these to identify tetrads of gametes and some other stages of meiosis. Following on from this, give students photographs or drawings of the stages of meiosis in the wrong order and ask them to sort them into the correct sequence. Students discuss the details of Meiosis I and II with the teacher, stress the importance of: • crossing over in prophase I • independent assortment in anaphase I and anaphase II. Show how this mirrors the behaviour of alleles in mono- and dihybrid inheritance.
CA	Students make notes on meiosis.
What about alleles that don't segregate – genetic linkage	
SA	Question and answer to establish that independent assortment is only possible for alleles that are on different chromosomes.
MA	Students examine how two linked genes behave as a single unit and produce the same ratios as a monohybrid cross. Class to discuss the effects of crossing over and understand how recombinant types can be formed.
CA	Students make notes on linked genes and crossing over.
How is a knowledge of genetics important in cross-breeding and inbreeding crops and stock animals?	
SA	Students discuss the concepts of inbreeding, cross-breeding and hybrid vigour in the context of selective breeding. Students examine hybrid vigour in terms of increased heterozygosity and action of dominant alleles. Show how inbreeding leads to decreased heterozygosity and therefore is used in the production of pure lines.
MA	If possible, arrange a trip to an agricultural institution to observe inbreeding and cross-breeding programmes in action.
CA	Students make notes on the programmes and the genetics of the programmes.
What about genes on sex chromosomes – sex linkage	
SA	Class to review from grade 10 the roles of the X and Y chromosomes in sex determination. Students examine how nondisjunction of the sex chromosomes can lead to unusual karyotypes and modified sexuality.
MA	Students discuss examples of genes carried on the X chromosome and why they can only be inherited by males. Students study genes carried on the X chromosome and, in particular, the pattern of inheritance of conditions such as red–green colour blindness that are determined by recessive alleles. Students practise analysing pedigrees showing sex-linked inheritance.
CA	Brief class discussion on the difference between sex-influenced traits and sex-limited traits.

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Answers to review questions

1. B
2. D
3. D
4. C
5. D
6. D
7. D
8. B
9. C
10. A

This section should fill approximately **6 periods** of teaching time.

3.2 Molecular genetics

Learning competencies

By the end of this section students should be able to:

- Describe the structure of a chromosome.
- Describe in detail the structure of the DNA molecule.
- Name the four nucleotides that build up the DNA molecule.
- Construct a model of DNA showing the base pair between complementary nucleotides.
- Describe the semi-conservative replication of DNA.
- Describe the significance of some of the uses of gene technology in forensic science (such as genetic fingerprinting).
- Describe how genetic fingerprints are produced.
- Define and give examples of cloning.
- Understand that genes can be cloned and explain in outline how this is achieved.
- describe, in outline, the procedures involved in genetic engineering and appreciate that whilst there are many advantages that result from the process, there are also some ethical concerns about some of the procedures.

Starting off

Again, some of this work will be a revision of material that the students covered in grade 10, but it is probably best to assume that only the basics have been memorised and to recap virtually all of that material before progressing.

The Students' Book begins unit 3 with an outline of the relationship between chromosomes, genes and DNA. This section begins with a slightly more detailed presentation of that topic. Get the students to recap their knowledge of globular proteins at the outset. Then they will be ready to appreciate just how DNA becomes wound round histone molecules to form nucleosomes. It is then probably sufficient to explain that these form sections of chromatin known as 'beads on a string', which become progressively compacted as the chromatin condenses to form a visible metaphase chromosome.

The activity of genes should be linked to the degree of condensing; genes are most active in the uncondensed chromatin and least active in the most condensed chromatin. If more detail is required, the diagram below can be used to extend the concepts.

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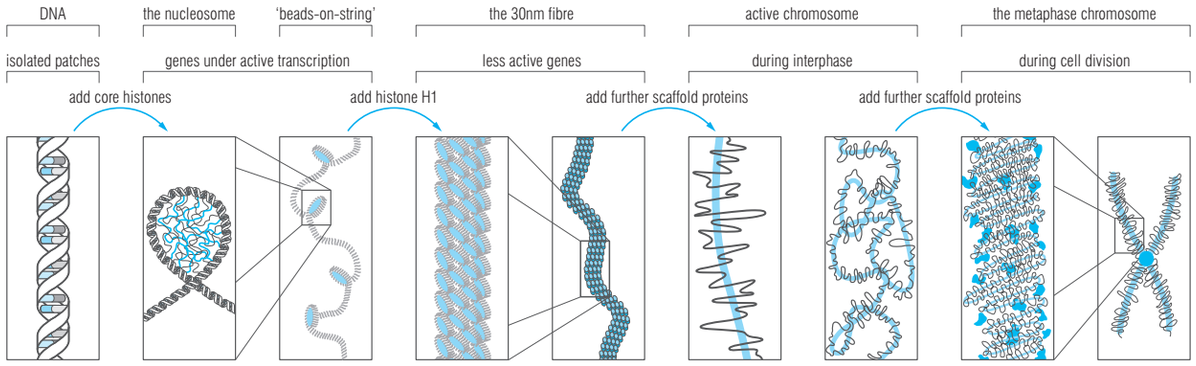


Figure 3.1

This would be an appropriate time to recap the differences between prokaryotic and eukaryotic DNA.

The basic structure of DNA has been covered in grade 10 and again in grade 11, so students should be familiar with the structure of nucleotides and the base-pairing rule, but it will not harm them to hear all of this again! However, what will be new is the concept of anti-parallel strands. This is a term that the students quite like once they have grasped the concept. The way it is explained in the text should give sufficient detail for this level.

Make sure that the students can differentiate between a *strand* of DNA and a *molecule* of DNA.

The practical opportunity to extract DNA is a straightforward practical and is explained in full detail in the Students' Book; however, the procedure is reproduced here for convenience.

Carry out the following.

1. Mix together the washing up liquid, the salt and the tap water and stir slowly (try to produce as little foam as possible) until the salt has dissolved. This mixture is called an extraction buffer.
2. Blend the chunks in the blender (this is to break open the cells).
3. Add the extraction buffer to the banana and mash!
4. Set up your water bath so that the temperature of the water is 60 °C.
5. Stand the banana and buffer in the water bath for 15 minutes. Try to maintain the temperature by adding hot or cold water as necessary.
6. Remove the beaker from the water bath and filter the banana mixture through a fine sieve or coffee filter paper into the other beaker. You should be left with a greenish liquid, which contains the banana fruit DNA.
7. Half fill a test tube with some of this filtrate.
8. Pour the ice-cold alcohol slowly down the side of the test tube. The alcohol will form a transparent layer on top of the banana mixture, as the alcohol is less dense.
9. Where the two liquids meet, the DNA, which was dissolved in the buffer mixture, will precipitate (come out of solution).
10. Remove the DNA from the ethanol/buffer with the pipette and place it in a Petri dish lid or on a tile.
11. Test the DNA with litmus paper to show that it really is *deoxyribonucleic acid*.

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No doubt the students will want to view it under the microscope to see if they can see the double helix. You will have to disappoint them!

The replication of DNA is, in essence, a straightforward concept to understand. What the students must appreciate is that:

- The strands must be separated – this is done by the enzyme helicase (ask them if they can work out the origin of the name).
- Each strand serves as a template for the creation of a second complementary strand.
- These new strands are assembled from free DNA nucleotides by the enzyme DNA polymerase (again, ask them to explain the origin of the name).
- Because of the base-pairing rule, the new strands will be complementary to the existing ones.
- Each new molecule of DNA contains one strand from the original molecule and one newly synthesised complementary strand.
- The two new molecules will, therefore, be identical.

See if the students can work out the origin of the term semi-conservative replication.

In practice, because of the anti-parallel nature of the molecule, the replication is not that simple, as DNA polymerase can only work continuously along one of the strands (the leading strand).

It is worth mentioning that knowledge of the process of semi-conservative replication has allowed the development of the polymerase chain reaction (PCR), which effectively mimics the natural replication of DNA. Explain that this has been invaluable in forensic science in amplifying the amount of DNA available for analysis.

The section on cloning is introduced by describing some traditional cloning techniques – such as taking cuttings and students may wish to take some cuttings as a simple practical opportunity.

The development of this traditional technique into the technique of micropropagation, capable of producing tens of thousands of plants from just one parent plant is something that the students could research.

The cloning of animals is more complex and students need to appreciate the need for:

- a cell capable of dividing that contains.
- a diploid nucleus.

It is worthwhile exploring with the students why a normal diploid cell cannot be used – why does it have to be an enucleated egg cell with a diploid nucleus inserted? This may lead in to a discussion of stem cells and their use in research and other areas.

If internet access is available, then the cloning process can be brought alive by the use of an interactive animation called 'click and clone'. The website is:

http://learn.genetics.utah.edu

Or you could just search 'click and clone' and it will produce this as the top option.

Once the fact of cloning mammals is established in their minds as an available technique, students could make a presentation on the cloning of humans, or human organs. This is an area that arouses strong feelings on both sides of the debate and should make for some interesting displays.

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Genetic engineering is, potentially, a huge topic that could fill many teaching periods many times over. However, the essence of gene transfer is described in figure 3.40. Students are usually quite happy with the concept of cutting and pasting genes from one organism to another using restriction enzymes as molecular scissors and ligase enzymes as molecular gluesticks.

Some of the products of transgenic bacteria are listed in the Students' Book; students could carry out research to find others.

The extension of genetic modification from modifying bacteria to modifying plants is dealt with briefly. Students usually find the idea of a real 'golden gun' quite amusing.

There is clearly scope for students to make a display about the advantages and disadvantages of genetic engineering. There is some material in the Students' Book about the various products from genetic engineering that could form part of the display together with the material on the potential advantages of genetic engineering and the moral and ethical issues surrounding gene technology, dealt with at the very end of the chapter.

Finally, we consider the process of genetic fingerprinting. The individual concepts of the various stages of genetic engineering are generally within the students' compass, it is the complexity of the whole process that needs careful explanation.

The main stages in preparing a genetic fingerprint are as follows:

1 DNA is isolated from the cells.

2 The DNA is cut into fragments using one or more restriction enzymes. The fragments that are obtained are treated with alkali to separate the strands of each DNA fragment.

3 The fragments are separated by gel electrophoresis. Smaller fragments (with a lower molecular mass) move further than larger fragments.

The use of the radioactive DNA probe is simply a means of making the fragments detectable by making them radioactive.

If the students appreciate this, they will probably be able to work through the detail of the process.

SA = starter activity MA = main activity CA = concluding activity	
What is the structure of DNA in a chromosome?	
SA	Students revise the structure of a chromosome and the relationship between genes and DNA from section 3.1.
MA	Students revise, from grade 11, the structure of DNA as a double helix of nucleotides. Students recall the base-pairing rule. Students discuss the importance of the stability and size of the DNA molecule in relation to its function as the genetic material. Students carry out activity 3.7 to show how DNA can be extracted. Detailed instructions on how to carry out this activity are given on pages 71-72 of this Teacher Guide.
CA	Students make an edible model of DNA in activity 3.6, to establish the base-pairing rule. The teacher should talk through the instructions in the textbook carefully with the students and ensure they understand what each component symbolises before constructing their model: if the foods/equipment listed are not available the teacher should try to find alternatives. The key point is that there are enough components of different colours to create an accurate representation of DNA.

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<table>
<tr><th colspan="2">The replication of DNA and cloning of organisms</th></tr>
<tr><td>SA</td><td>Students recall the structure of the DNA molecules and, in particular, the concept of base pairing.</td></tr>
<tr><td>MA</td><td>Class to discuss the principles of semi-conservative replication in outline. Use figure 3.36 as a basis for this. Students produce a table such as the one below to describe the functions of the various molecules involved in the process
<table>
<tr><th>Molecule</th><th>Function in semi-conservative replication</th></tr>
<tr><td>DNA helicase</td><td></td></tr>
<tr><td>Unzipped single strand of DNA</td><td></td></tr>
<tr><td>Free nucleotides</td><td></td></tr>
<tr><td>Bases on the nucleotides</td><td></td></tr>
<tr><td>DNA polymerase</td><td></td></tr>
</table></td></tr>
<tr><td>CA</td><td>Students also make a flow chart showing the stages involved in semi-conservative replication of DNA.</td></tr>
<tr><th colspan="2">How are organisms cloned?</th></tr>
<tr><td>SA</td><td>Question and answer to establish the nature of a clone.</td></tr>
<tr><td>MA</td><td>Class discussion traditional methods of cloning such as taking cuttings of plants, and how this has been modified by the introduction of micropropagation.
Students could take their own cuttings if time permits.
Students examine how Dolly, the first sheep clone, was produced.</td></tr>
<tr><td>CA</td><td>Students could debate the acceptability of cloning humans.</td></tr>
<tr><th colspan="2">The ethics of cloning</th></tr>
<tr><td>SA</td><td>Students vote, without any preparation, on whether human cloning should ever be allowed. Record the results at the front of the class; this is the first part of activity 3.9.</td></tr>
<tr><td>MA</td><td>Students complete activity 3.9 in groups, each group nominating a spokesperson to present its opinion to the rest of the class.</td></tr>
<tr><td>CA</td><td>Students vote again on whether human cloning should ever be allowed, and compare the results to those from the initial vote. If there is time the class can discuss the reasons for any change.</td></tr>
<tr><th colspan="2">What is genetic engineering?</th></tr>
<tr><td>SA</td><td>Students recall how selective breeding has been used to modify organisms over a long period. Students remember that, now, through the process of genetic engineering, this can be achieved in one generation.</td></tr>
<tr><td>MA</td><td>Students discuss the main stages of genetic engineering as shown in figure 3.40 and make notes.
Students discuss the potential benefits and concerns of genetic engineering</td></tr>
<tr><td>CA</td><td>Students carry out activity 3.12 and produce posters.</td></tr>
</table>

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<table>
<tr><th colspan="2">How can gene technology be used in forensic science?</th></tr>
<tr><td>SA</td><td>Students examine the difference between conventional fingerprinting and genetic fingerprinting.</td></tr>
<tr><td>MA</td><td>The process of genetic fingerprinting should be discussed and students could then be given a partially labelled diagram to complete and a table to complete, such as the one below, to reinforce understanding by applying the information in a slightly different way.
<table>
<tr><th>What must happen?</th><th>How is it done?</th></tr>
<tr><td>DNA must be extracted</td><td></td></tr>
<tr><td>Fragments of DNA must be separated</td><td></td></tr>
<tr><td>Separated strands of DNA transferred to a membrane</td><td></td></tr>
<tr><td>Strands must be made radioactive</td><td></td></tr>
<tr><td>Positions of strands must be shown</td><td></td></tr>
</table></td></tr>
<tr><td>CA</td><td>Students debate the ethical and moral considerations of using gene technology.</td></tr>
</table>

Answers to review questions

1. C
2. B
3. A
4. A
5. C
6. A
7. D
8. D

3.3 Protein synthesis

This section should fill approximately **5 periods** of teaching time.

Learning competencies

By the end of this section students should be able to:

- Describe how the flow of information in a cell starts from the code on DNA and ends with proteins being synthesised.
- Understand the nature of the genetic code.
- Describe the roles of DNA, mRNA, tRNA and ribosomes in protein synthesis and understand the processes of transcription, translation and gene expression.
- Understand that protein synthesis depends on having a supply of amino acids which, in animals, come from the food they eat.
- Understand the different roles proteins have in cells and in the body.

Starting off

It is as well at the outset to give students an overview of the whole process of protein synthesis. In the Students' Book, figure 3.45 and the accompanying

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notes cover this. Get the students to appreciate what is behind the names of the processes:

- Transcription (literally 're-writing') – the code in the DNA is re-written into another nucleic acid code, the RNA code.
- Translation – the nucleic acid code is translated from a code into the product it codes for – a protein.

Teaching notes

Before embarking on a description of protein synthesis, it is necessary to establish the nature of the genetic code as a:

- triplet code
- degenerate code
- universal code
- non-overlapping code.

Ask students to consider whether genetic engineering would have made the progress it has if the genetic code were not universal.

The two different representations of the DNA code can be used to ask students to work out all the possible codes for two or three amino acids. Students now need to understand something that is not intuitive; they need to appreciate that:

- Only one strand of the DNA molecule is actually a coding strand – the sense strand (the other – the anti-sense strand – does not carry the code).
- In transcription, the *antisense* strand is used as the template strand.

When they think about this in terms of complementary base pairing, they should realise that by using the antisense strand as the template, the strand of mRNA produced will be complementary to the antisense strand and, therefore, equivalent to the sense strand.

Begin the description of transcription by reminding the students of replication. This will help with understanding the process. If they have the concepts described above in place, they will find transcription quite straightforward.

Post-transcriptional modification is not something that appears necessary until it is pointed out that there are regions of non-coding DNA *within* a gene and that these will be copied to the mRNA molecule. Once this is understood, the need to remove the copied introns is accepted readily.

Translation involves a little more thought than does transcription. Several things must come together for the process to happen. Again, these are not intuitive, but if students will better appreciate the events that take place during transcription if they are presented with the need for the following to happen:

- Amino acids to be transferred to the ribosomes (the role of transfer RNA).
- The mRNA to have *all* its codons read by the ribosome (so all the mRNA must pass through the ribosome).
- Some mechanism that brings the amino acid to the ribosome *that is specified by the part of the mRNA that is in the ribosome* (a recognition mechanism).

Begin by reminding them of the need for amino acids to form peptide bonds to build the protein molecule. For this to happen, two amino acids must be held in close proximity in the ribosome.

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Next get them to look at the structure of tRNA and the ribosome – there are three sites in each ribosome that can temporarily hold a tRNA molecule. If two tRNA molecules with amino acids attached are held in adjacent sites, they can react to form a peptide bond.

Next introduce the idea of codon and anticodon as a recognition mechanism and all the pieces are in place for the students to analyse and appreciate the steps of translation as shown in figure 3.51.

Having considered the process in eukaryotic cells, a brief treatment of the differences in prokaryotic cells is given.

Students should have some concept of the many different fates of the proteins that are synthesised. Some of these are given in table 3.2, but students could research other functions.

They should be aware that we need a total of 20 amino acids to synthesise all the proteins in our bodies, and that most of these come from the food we eat. However, it is as well to introduce the concept of essential and non-essential amino acids together with the process of transamination as a means of synthesising non-essential amino acids.

The final section deals with the regulation of gene action. Students will have had at the back of their minds the question 'What makes genes work?'. This is relatively easily answered at one level by explaining that there are:

- transcription factors that turn genes on.
- other factors that silence genes in a range of ways.

However, the more thoughtful students will want to know where the transcription factors come from. This takes us into the idea of a 'cascade' of transcription factors, produced first of all by the zygote and influencing the cells that result from the first divisions of the zygote. These cells then produce other factors that influence the next generation of cells … and so on.

The use of the anti-cancer drug tamoxifen is explained in the Students' Book as an application of our knowledge of transcription factors.

SA = starter activity MA = main activity CA = concluding activity	
How does a cell 'know' to make a protein?	
SA	Use question and answer to establish that: • the genetic code (for the proteins) is held in DNA in the nucleus • the code must be re-written (transcribed) to messenger RNA to leave the nucleus – the DNA is too big • the code in the messenger RNA must be translated into a sequence of amino acids by the ribosomes • amino acids are brought to the ribosomes by transfer RNA. Get students to produce a flow chart to summarise this.

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<table>
<tr><td>MA</td><td>Introduce the concept of sense and antisense strands of DNA.
Students work out what would happen during replication of:
• a sense strand – clearly an antisense strand is produced
• an antisense strand – a sense strand is produced
They should now be able to explain the need for DNA to be double stranded, with sense and antisense strands.
Next, students discuss the nature of the genetic code and understand that it is:
• a triplet code
• non-overlapping
• universal
• degenerate
Give the students a copy of the DNA genetic code, showing all 64 triplets. Ask them to suggest why some triplets are ‘stop’ codes.</td></tr>
<tr><td>CA</td><td>Students examine why a universal code makes genetic engineering possible.</td></tr>
<tr><td colspan="2">How does transcription take place in a eukaryotic organism?</td></tr>
<tr><td>SA</td><td>Class to review (from grade 11) the differences between DNA and RNA.</td></tr>
<tr><td>MA</td><td>Question and answer to establish that the antisense strand of DNA must be transcribed to produce a sense strand of RNA.
Students discuss transcription with the teacher, use figure 3.48 as a basis and make notes. Also, to reinforce learning, get Students list similarities and differences between transcription and replication. They could complete a table like the one below:
<table>
<tr><th>Feature of process</th><th>Replication</th><th>Transcription</th></tr>
<tr><td>How much of DNA ‘unzips’</td><td></td><td></td></tr>
<tr><td>Which strand(s) are copied?</td><td></td><td></td></tr>
<tr><td>New molecule that is made in the process</td><td></td><td></td></tr>
<tr><td>Bases involved in new molecule</td><td></td><td></td></tr>
<tr><td>Enzyme that assembles the new molecule</td><td></td><td></td></tr>
</table></td></tr>
<tr><td>CA</td><td>CLass to review transcription and students write a brief summary.</td></tr>
<tr><td colspan="2">How does translation take place?</td></tr>
<tr><td>SA</td><td>Class to discuss the things that need to happen in the ribosome for a polypeptide chain to be assembled. Initially, limit this to:
• mRNA brings the code to the ribosome
• tRNA brings the amino acid
• there is recognition between a codon on the mRNA and tRNA carrying the appropriate amino acid
• all the mRNA passes through the ribosome for complete translation.</td></tr>
<tr><td>MA</td><td>Class to use figures 3.50 and 3.51 and the account in the textbook to discuss translation.
A cut and stick activity modelling translation is a useful way to reinforce learning. A suitable activity is described at: http://room114.wikispaces.com/Protein+Synthesis</td></tr>
<tr><td>CA</td><td>Students examine how protein synthesis in prokaryotic organisms is different to the process already described.</td></tr>
</table>

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What happens to the proteins synthesised?	
SA	Students recall some of the functions of proteins. In particular, that nearly all enzymes are proteins.
MA	Students recall that all metabolic pathways are controlled by enzymes. Students research metabolic pathways to show how enzymes are involved in: • controlling pathways such as respiration and photosynthesis • controlling the manufacture of structural proteins such as haemoglobin. Students produce charts to show the flow of information in a cell leading to the activation of specific metabolic pathways. They could follow the general format: Gene → mRNA → protein → catalyses reaction → product/stage in metabolic process activated
CA	Class to review protein synthesis from gene through to product formed.
What controls gene expression?	
SA	Tell students that all their cells have the gene that determines their eye colour. So why aren't their toes the same colour?
MA	Question and answer to establish the concepts of activating genes and inhibiting genes. Class to discuss transcription factors and gene silencing as methods whereby this is achieved. Students make notes.
CA	Student produce a small display on how gene silencing might cure AIDS or cancer.

Answers to review questions

1. B
2. D
3. D
4. A
5. B
6. B
7. C
8. D
9. D
10. D

3.4 Mutations

This section should fill approximately **5 periods** of teaching time.

Learning competencies

By the end of this section students should be able to:

- Explain what is meant by the term mutation.
- Describe some of the different types of mutations.
- Describe and explain some of the causes of mutations.
- State the spontaneity of a mutation.
- Describe and explain some of the consequences of mutations.
- Give examples of inheritable mutations.

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Starting off

The starting point for this section must be an understanding of the term mutation. The key ideas about mutations that the students must understand are:

- They involve a change to the DNA of an organism.
- The change is heritable.
- The change is often random and spontaneous.
- The rate of mutations can be increased by environmental factors.

Teaching notes

At the outset, establish that mutations occur on a range of different scales, from parts of chromosomes to a single base pair. The latter, point mutations, are the easiest for the students to relate directly to protein structure and function, as a change in a single base in the DNA will result in a corresponding change in the mRNA.

Get students examine that point mutations usually occur when the DNA is replicating and can be either:

- substitutions
- deletions
- additions.

Discuss substitutions first, as these are the most straightforward of all the mutations. Remind students of the degenerate nature of the genetic code so that they can understand that a substitution need not result in a change in amino acid coded for by the triplet. Also show them that a substitution may result in a stop code being generated, which will result in a non-functional protein.

Sickle-cell anaemia is described as an example of the potential effect of a single base substitution.

Introduce deletions and additions as mutations that have bigger effects than substitutions. Ask the students to see if they can work out why this may be. Give them a DNA sequence of, say, 30 bases and ask them to:

- Divide the sequence into triplets.
- Re-write the sequence with base 7 missing (a deletion).
- Re-write the sequence with an extra base before base 8 (an addition).
- Divide the two new sequences into triplets.
- Compare these triplets with the original triplets.

The students can normally observe that this type of mutation alters every triplet after the point of the mutation.

The next section presents some quite staggering data on the frequency and extent of mutations. The students will have difficulty in getting their minds around these numbers. But they should realise that mutation is an everyday event in the human body.

The impact of mutations can be discussed at several levels.

- What is the impact on the cell in which the mutation occurs?
- What is the impact on the organism in which the mutation occurs?
- Is there any effect on the next generation?

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Students should realise that this depends not just on the nature of the mutation but on where the mutation takes place. A serious mutation that kills a skin cell is of no significance to the organism. A mutation in genes controlling cell division may have a bigger impact by leading to the formation of a tumour.

The acquired resistance to antibiotics in bacteria as a result of mutation is an example of a beneficial mutation (for the bacteria!).

The section concludes with a brief treatment of some chromosomal mutations. Ask students why these mutations nearly always result in the death of the cell.

<table>
<tr><th colspan="2">SA = starter activity MA = main activity CA = concluding activity</th></tr>
<tr><th colspan="2">What are mutations? (1)</th></tr>
<tr><td>SA</td><td>Question and answer to establish an accurate definition of the term mutation.
Students examine the difference between point mutations and other kinds of mutations.</td></tr>
<tr><td>MA</td><td>Students examine the difference between the types of point mutations. Classify them into frameshift and non-frameshift mutations and describe the various types.
Students examine that the mutations can impact on:
• the mRNA sequence
• the amino acid sequence.</td></tr>
<tr><td>CA</td><td>Students make notes.</td></tr>
<tr><th colspan="2">What are mutations? (2) – reinforcement activity</th></tr>
<tr><td>SA</td><td>Students recall the nature and types of mutations discussed in the previous lesson.</td></tr>
<tr><td>MA</td><td>A good reinforcement activity for this topic can be found at:
http://www.lessonplansinc.com/science.php/biology/lessonplans/C104/
Students carry out the activity.</td></tr>
<tr><td>CA</td><td>Students make a mini-display on point mutations.</td></tr>
<tr><th colspan="2">What are the causes and consequences of mutations?</th></tr>
<tr><td>SA</td><td>Students discuss with the teacher the data on the extent of mutations.</td></tr>
<tr><td>MA</td><td>Students appreciate that:
• mutations occur spontaneously all the time, at random
• certain environmental factors increase the rate at which mutations occur.
Get students to research and list as many environmental factors as possible that increase the rate of mutation. They could produce a table like the one below:
<table>
<tr><th>Factor</th><th>Increase or decrease mutation rate</th><th>How effect is brought about</th></tr>
<tr><td>UV radiation</td><td>Increase</td><td>Damages structure of DNA</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
</table>
</td></tr>
<tr><td>CA</td><td>Students discuss with the teacher the possible consequences of mutations.
Students make notes.</td></tr>
</table>

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What about chromosome mutations?	
SA	Students recall that mutations are any alterations in the DNA and explain that this can involve whole chromosomes or sections of chromosomes.
MA	Students learn that many of the errors that occur to give rise to point mutations (inversions, deletions, duplications) can also occur on a larger scale. Class to discuss the impact of these chromosomal mutations and students make notes.
CA	Class to review all types of mutations.
Mutations: summary	
SA	Students suggest, discuss and agree on single sentence definitions of the different types of mutations they have learnt about and these are written up at the front of the classroom.
MA	Students complete activity 3.14.
CA	Students present their posters to the class with brief explanations.

Answers to review questions

1. C
2. C
3. D
4. D
5. A

Answers to end of unit questions

1. a) The DNA molecule is:

   double stranded

   arranged in a double helix

   each strand made of nucleotides

   nucleotide made of sugar, base and phosphate

   two strands joined by hydrogen bonds

   complementary base pairing of A-T and C-G

   link between phosphate and sugar in nucleotides in a strand

   Note: all need to be clearly labelled if only a diagram is used.

   b) Three of:

   mRNA is shorter than DNA

   mRNA is single stranded whereas DNA is double stranded

   mRNA contains uracil whereas DNA contains thymine

   mRNA contains ribose whereas DNA contains deoxyribose

   c) Two of:

   tRNA is looped/hairpin shape whereas mRNA is straight

   tRNA has base pairing whereas mRNA does not

   tRNA has an amino acid attachment site whereas mRNA does not

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2. a) UAA GGG CGA UUU GUC

   Perfectly correct = 2 marks, 1 error = 1 mark.

   b) i) Deletion removes a base from a sequence (sequence redrawn with a base missing).

   ii) Addition adds a base to a sequence (sequence redrawn with base added).

3. a) Four of:

   DNA strands in region of gene separate/unzip

   free RNA nucleotides used

   assembled into a strand

   complementary to sequence on DNA

   by RNA polymerase

   Ignore references to post-transcriptional modification.

   b) In a prokaryotic cell:

   transcription and translation are coupled

   transcription takes place in cytoplasm

   no post-transcriptional modification occurs

4. a) A gene is a section of DNA that codes for a specific protein/determines a specific feature.

   An allele is a specific 'version' of a gene.

   Dominant refers to an allele that is expressed in the heterozygote.

   b) Breed the plant with a white-flowered plant.

   If the parent plants were homozygous for white alleles, the offspring would be pp.

   If the parent plants were homozygous – all offspring Pp.

   If parent plant was heterozygous, some/half of the offspring would be Pp and some would be pp.

5. a) Four of:

   controlled by a pair of alleles

   'black' allele and 'white' allele

   show incomplete dominance

   evidence – when black and white alleles together, get blue

   evidence – crossing two blues/heterozygotes gives 1:2:1 ratio

   b) Four of:

   blue and white offspring

   1 : 1 ratio

   Parents Bb x bb

   Gametes B b b

   Offspring Bb bb

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6. a) i) All affected individuals are male; it skips a generation.

ii) Two of:

two unaffected parents can produce an affected child

so parents carry the allele but do not express it

not possible if allele is dominant

only possible if allele is recessive

b) Any of: 4, 8, 9, 10, 23, 25, 26

Plus two marks for suitable logic:

either

father was affected

must pass his affected X chromosome to daughter

or

son is affected

must have inherited affected X chromosome from mother

c) Sons – X^bY

All X chromosomes of parents are X^b/are affected

Daughters X^bX^b

All X chromosomes of parents are affected so must inherit two affected X chromosomes

7. a) Prophase – chromosomes condense and crossing over occurs

nuclear membrane disappears and spindle forms.

Metaphase – homologous chromosomes align opposite each other.

Anaphase – homologous chromosome pulled to opposite poles.

Telophase – two haploid nuclei form at the poles.

b) i) If not linked:

would expect a 1:1:1:1 ratio

due to independent assortment of alleles

four gametes possible in heterozygote/CS Cs cS cs possible

only one gamete from homozygous recessive/cs

If linked:

two gametes from heterozygote/CS cs

still only one type from homozygous recessive / cs

only two types predicted coloured smooth and colourless wrinkled

other types are recombinants

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ii) Parents CScs x CScs

Gametes CS cs CS cs

Offspring CSCS CScs CSCS CScs

50% coloured smooth : 50% colourless wrinkled

8. a) i) Low level until 1994

then sudden/sharp/great increase

continues to remain high/to increase slowly/steadily

with dip in 1997–1998

ii) Mutation giving resistance always present/occurs several times

as some resistant bacteria always present

sharp increase in use of penicillin

in 1993 (some time just before sharp increase in numbers)

gives resistant types a survival/selective advantage

survive and reproduce in greater numbers than others

b) Conjugation

Transduction

Transformation

9. a) Incubate DNA with a restriction enzyme to cut it into fragments; separate the fragments by gel electrophoresis; carry out Southern blotting to transfer the fragments to a membrane; add a radioactive DNA probe; prepare a radiograph of the membrane. This reveals a pattern of fragments called a DNA fingerprint.

b) Yes. All the fragments in the child's fingerprint are common with Larry or Mary, some are only found in Larry; some of Bob's are not found in the child.

10. a) i) 153/156; 3 bases per amino acid/3 bases per amino acid plus stop code.

ii) Gene for insulin is transcribed to give mRNA, which travels to ribosomes and is translated to insulin protein/polypeptide.

b) i) A gene is cut from DNA using restriction enzymes; plasmids are extracted from bacteria and cut open with the same restriction enzymes; the plasmids have sticky ends; the plasmids inserted into bacteria.

ii) Any two suitable concerns (use the list in the Students' Book as starting point) and suitable methods of addressing these concerns.

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Answers to end of unit crossword puzzles

Crossword 1

Across

3 centromere
6 sex-limited
8 dominant
9 trait
12 heterozygous
14 dihybrid
17 genotype
20 homologous
21 sex-linkage
22 allele
23 independent assortment
24 Punnett square

Down

1 recessive
2 crossing over
4 diploid
5 test cross
7 haploid
10 homozygous
11 sex influenced
13 multiple allele
15 DNA
16 codominant
18 linkage
19 phenotype

Crossword 2

Across

2 substitution
5 plasmid
6 complementary
7 cloning
8 polymerase
11 transcription
12 mutation
16 nucleotide
18 transcription factor
19 messenger
20 translation
21 helicase
22 noncoding

Down

1 histone
3 semiconservative
4 ligase
9 restriction
10 triplet
13 frame shift
14 base pairing
15 PCR
17 universal

Further resources

http://www.practicalbiology.org/area-index-pages/genetics/ – activities and resources on genetics

http://www.societyofbiology.org/education/educational-resources/genetics – more resources on genetics, including games and quizzes

http://www.biostudio.com/demo_freeman_protein_synthesis.htm – protein synthesis animation

www.yourgenome.org – Wellcome Trust Sanger Institute website with student resources and further information on genome science and issues

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