Unit 28: Understand the Principles of Inheritance and Genetic Manipulation

Unit code: D/600/9463

QCF Level 3: BTEC National

Credit value: 10

Guided learning hours: 60

Aim and purpose

This unit aims to provide learners with an understanding of the principles of inheritance and genetic manipulation and how these can be applied in practice. This unit is primarily aimed at learners within a centre-based setting looking to progress into the sector or further education and training.

The aim of this unit is to develop knowledge and understanding of the principles of inheritance and the applications of genetic manipulation in animals.

Unit introduction

Around 5,000 years ago people understood how to cross-breed horses and date palm trees. The study of genes and genetics dates back to the mid-1800s but the majority of information about genes and how they interact has been explained only within the last few decades. A good understanding of how characteristics are inherited is essential to keep up with the fast pace of change in the world of genetics. Genetics and genetic manipulation are increasingly impacting on other scientific disciplines, contributing towards advances in forensic science, biomedical sciences, epidemiology, global food provision, tracking and identification of populations and environmental conservation.

Examining the molecular structure of DNA is the basis of understanding the mechanism of how characteristics may be passed from parent to offspring. It is important that learners have an awareness of both Mendelian and population genetics in order to understand and predict the potential consequences that natural selection and genetic manipulation may have on both domestic and wild populations.

There are often conflicts between the scientific community and the general public when genetic manipulation is discussed in the media. Learners need the ability to identify how and why genetic manipulation techniques are used in science as well as being able to evaluate objectively the advantages and disadvantages of these techniques to organisms, society and the environment.

Learning outcomes

On completion of this unit a learner should:

1 Understand the molecular basis of inheritance

2 Understand the principles of Mendelian genetics

3 Understand the principles of population genetics

4 Know the principles of genetic manipulation.

Unit content

1 Understand the molecular basis of inheritance

Definitions and functions: nucleus; genome; chromosomes; genes; nucleic acids; bases

Nucleic acid structure: DNA; RNA (tRNA, mRNA, rRNA)

DNA replication: comparison of conservative and semi-conservative replication; enzymes involved at each stage; replication forks; Okazaki fragments; proofreading and repair

Chromosomal structure: chromatin (euchromatin, heterochromatin); nucleosomes; genes; alleles; telomeres; chromatids; karyotypes

2 Understand the principles of Mendelian genetics

Inheritance: continuous and discontinuous variation; heritable characteristics; dominant and recessive alleles; homozygous and heterozygous genotypes

Chromosomal behaviour during meiosis: crossing over; independent assortment

Inheritance ratios: monohybrid and dihybrid crosses; genetic diagrams to F2 generations; phenotypic and genotypic ratios

3 Understand the principles of population genetics

Spontaneous and induced mutations: point, insertion, deletion; duplication, translocation; frameshift, nonsense, missense, neutral and silent; the effect of mutations on variation (harmful, beneficial and neutral)

Evolution and natural selection: adaptations of species leading to evolution (a change in the survival or reproductive rates of different genotypes within populations); effects of stabilising, directional and disruptive selection; sexual selection

Hardy-Weinberg: gene pools; calculation of allele frequency within a population; genetic drift; gene flow; effect of non-random mating on frequency of homozygous alleles; importance of the Hardy-Weinberg equilibrium and conditions for equilibrium to be met (random mating, large population size, no effect of natural selection on the specified alleles, no migration or mutation); Hardy-Weinberg equation ($p^2+2pq+q^2=1$)

4 Know the principles of genetic manipulation

Techniques: DNA extraction; gel electrophoresis; recombinant DNA technology; use of restriction enzymes; use of vectors in transduction and transfection; marker genes; polymerase chain reaction; knockout mice

Applications: insulin production; alpha-1 antitrypsin production; gene therapy; DNA fingerprinting, genetic testing (eg SCID in Arabian horses, von Willebrand's disease in dogs, Freemartinism in cattle); 'pharming'(production of medically useful products in the milk of goats, sheep and cows); gene targeting for analysis of gene regulation and function

Advantages and disadvantages: commercial, social and ethical issues; practical limitations of techniques and potential ways in which these may be overcome

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the structure of DNA [RL, SM]		
P2 describe DNA replication [IE, RL]		
P3 describe chromosomal structure [IE, RL]		**D1** evaluate chromosomal structure in terms of the inheritance of characteristics
P4 explain how the behaviour of chromosomes during meiosis leads to variation [IE, RL]	**M1** summarise how the expression of a genotype can be affected by environmental factors	
P5 explain monohybrid and dihybrid inheritance ratios [IE, RL]		
P6 describe the process of evolution through natural selection [IE, CT, RL]		
P7 describe the effect of mutations on variation [IE, RL]		
P8 explain evolution in terms of the Hardy-Weinberg Principle [IE, RL]	**M2** explain the importance of genetic variability within populations using given species.	
P9 describe techniques used in genetic manipulation [IE, SM]		**D2** evaluate the impact of advancing technology on potential applications of genetic manipulation.
P10 identify applications of genetic manipulation [IE, RL]		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P11 evaluate the advantages and disadvantages of genetic manipulation techniques. [IE, RL, EP]		

PLTS: This summary references where applicable in the pass criteria, in the square brackets, the elements of the personal, learning and thinking skills. It identifies opportunities for learners to demonstrate effective application of the referenced elements of the skills.

Key	IE – independent enquirers	RL – reflective learners	SM – self-managers
	CT – creative thinkers	TW – team workers	EP – effective participators

Essential guidance for tutors

Delivery

Delivery of this unit will involve practical and written assessments, visits to suitable collections and will link to work experience placements.

Practical work, preferably carried out by learners themselves should be used wherever possible to illustrate concepts. It is recognised that the facilities required for this are not readily available in the standard teaching laboratory and visits to industrial laboratories are strongly recommended where available. Industry liaison, enabling learners to speak with and learn from scientists involved in using genetic techniques on a day-to-day basis, will help to relate the theory in this unit to its wide-reaching applications.

Using paper or modelling clay can help learners appreciate the 3D structures of nucleic acids for learning outcome 1, and there are many online animations available to illustrate the process of DNA replication. It is helpful if learners are aware of the properties and actions of enzymes before discussing their impact. Learners should observe the differences between species' karyotypes. Polyploidy should be referred to but discussions should be limited to diploid species to avoid confusion.

For learning outcome 2, learners should have access to microscopes and slides with the different stages of meiosis along with animations of chromosomal behaviour. Modelling clay of different colours can be used to illustrate how chromosomes cross over during meiosis. Examples of monohybrid and dihybrid inheritance in animals should be used, but reference to plant genetics may be used for a full explanation if required.

Tutors should ensure that learners are confident with the mathematical skills required for learning outcomes 2 and 3. It may be helpful to practise algebraic equations and probability calculations before and during their applications in context. Games may be a good way to motivate and engage learners during the study of mutations and their effects, and can be tied in directly with the study of learning outcome 1. Learners may have preconceived ideas about this subject, and should be encouraged to share the basis of their views before exploring the scientific principles involved in the theories of natural selection and evolution. They should be familiar with how scientific theories come to be accepted and have acess to both contemporary and historical reporting on scientific discoveries.

Learning outcome 4 should be practically based wherever possible and evidence from laboratory investigations can be used as part of the evidence for the assessment criteria. Case studies of geneticists and other scientists could be used as a teaching tool for this section, and there are several online simulations of experiments that learners can access. Learners should also be encouraged to access contemporary genetics journals in order to be aware of practical limitations of techniques, how these may be overcome and the potential applications of new and improved techniques.

Outline learning plan

The outline learning plan has been included in this unit as guidance and can be used in conjunction with the programme of suggested assignments.

The outline learning plan gives **an indication of the volume of learning it would take the average learner** to achieve the learning outcomes. It is **indicative and is one way of achieving the credit value**.

Learning time should address all learning (including assessment) relevant to the learning outcomes, regardless of where, when and how the learning has taken place.

Topic and suggested assignments/activities and/assessment
Introduction and overview of unit.
Establishing prior knowledge and discussing concept of inheritance.
Recap cellular ultrastructure, introduce genes, chromosomes and DNA.
Structure and function of nucleic acids.
DNA replication.
Chromosomal structure.
Animal-based research task comparing the differences between karyotypes in different species.
Assignment 1: Structure and Function of DNA and Chromosomes (P1, P2, P3, D1) Tutor introduces assignment brief
Personal study.
Learner presentations – The Genetic Code.
Individual support.
Section summary.
Personal study.
Assignment 1: Structure and Function of DNA and Chromosomes (P1, P2, P3, D1)
Mendel and the study of genetics – phenotypes and genotypes.
Assignment 2: Monohybrid and Dihybrid Inheritance (P5) Tutor introduces assignment brief
Monohybrid and dihybrid inheritance, probability calculations, genetic diagrams.
Virtual investigation into Drosophila genetics.
Personal study.
Assignment 2: Monohybrid and Dihybrid Inheritance (P5)
Individual support.
Recap of meiosis, in-depth look at behaviour of chromosomes at prophase I and metaphase I.
Assignment 3 – Inheritance and Variation (P4, M1) – Tutor introduces assignment brief
Personal study.
Individual support.
Assignment 3: Inheritance and Variation (P4, M1)
Personal study.
Mutations, with guided task for learners to find specific examples of effects of mutations on variation.
Personal study.
Lamarck, Darwin, Wallace: approaches to evolution. Learner debate on evolutionary theories and evidence.
Natural selection: selective pressures and comparison with artificial selection – practical work on antibiotic resistance.
Personal study.
Hardy-Weinberg equilibrium and use of calculations.
Assignment 4: Natural Selection and Evolution (P6, P7, P8, M2) Tutor introduces assignment brief

Topic and suggested assignments/activities and/assessment
Section summary.
Personal study.
Assignment 4: Natural Selection and Evolution (P6, P7, P8, M2)
Personal study.
Individual support.
Assignment 5: Genetic Manipulation (P9, P10, P11, D2) Tutor introduces assignment brief
Establish level of knowledge about genetic manipulation, discussion of opinion based on prior knowledge.
Genetic manipulation techniques: theory and practical experience of DNA extraction and gel electrophoresis.
Guided learner research task: applications of genetic manipulation.
Personal study.
Learner presentations: current techniques and applications in genetic manipulation.
Discussion and conclusions: current and potential uses of genetic manipulation, with focus on technologies involved.
Personal study.
Commercial, social and ethical considerations of genetic manipulation.
Individual support.
Assignment 5: Genetic Manipulation (P9, P10, P11, D2)
Individual support.
Unit review.

Assessment

For P1, learners must describe the structure of DNA in detail, including its chemical composition. This may be assessed at the same time as P2 and P3, and evidence could be a labelled poster, model, part of an illustrated essay or pictorial presentation.

For P2, the stages of DNA replication must be described, including the direction of replication, names and roles of enzymes at each stage. This may be assessed at the same time as P1and P3 and suitable evidence would be in the same format.

P3 requires learners to describe chromosomal structure in detail. This may be assessed at the same time as P1 and P3, or at the same time as P4. Suitable evidence would be a model, illustrated report, presentation or labelled poster.

P4 requires learners to explain how the behaviour of chromosomes during meiosis leads to variation. There must be an outline of the process of meiosis and a specific description of prophase I and metaphase I linked to how variation results. Suitable evidence would be a poster or illustrated essay.

For P5, learners must give at least one example each of monohybrid and dihybrid inheritance, constructing genetic diagrams that illustrate the resulting genotypic and phenotypic ratios. There must be an accompanying explanation of the ratios. Suitable evidence would be in the same format as for P4.

For P6, learners must describe the processes of natural selection that lead to evolution, with at least two supporting examples. Evidence for this may be an illustrated essay, pictorial presentation or poster. P8 may be assessed alongside P6.

For P7, learners must describe the effects of at least five mutations from the unit content, with an outline of how they occur. Suitable evidence would be an essay or presentation.

P8 requires learners to use the Hardy-Weinberg Principle to explain how evolution occurs, with an example population analysed by applying the Hardy-Weinberg equation. Suitable evidence would be a poster or report. This may be assessed at the same time as P6.

P9 requires learners to describe genetic manipulation techniques as described in the unit content. If learners have carried out any of the techniques, the laboratory reports generated may be used as part of the evidence, along with descriptions of those that have not been carried out. Methods, materials and timescales must be included.

For P10, learners must identify applications of genetic manipulation techniques. This could be as part of a project where techniques are described and evaluated, and assessed alongside P9 and P11. Suitable evidence would be a short report on the applications of each technique described in P9.

P11 requires learners to evaluate the advantages and disadvantages of genetic manipulation techniques. The commercial, social and ethical issues must be considered and a conclusion drawn from the arguments put forward. P11 may be assessed alongside P9 and P10 and suitable evidence would be an essay, poster or as part of a project.

To achieve M1, learners must describe how a genotype is expressed and then describe how at least three environmental factors may alter the expression of the genotype. Suitable evidence would be an illustrated essay or report or fictional newspaper/magazine article.

For M2, learners must use two example populations of species to explain the importance of genetic variability. One should be where genetic variability is low and one where it is high, with the resulting consequences for the population described in detail. Suitable evidence would be an illustrated essay, pictorial presentation or short video produced by learners (with an accompanying timeline or transcript to show where the criteria have been met).

D1 requires learners to explore chromosomal structure and evaluate how the structure influences the inheritance of characteristics. Reference to karyotypes must also be made. Suitable evidence would include an illustrated essay, pictorial presentation or poster. D1 could be assessed as an extension to P3 and M1.

For D2, learners need to evaluate how technological advances may impact on genetic manipulation techniques. They should consider historical advances and suggest how existing techniques might be improved. Suitable evidence would be an essay or presentation. D2 could be assessed alongside P9, P10 and P1.

Programme of suggested assignments

The following table shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, D1	Structure and Function of DNA and Chromosomes	You must describe the structural components of DNA and chromosomes, outlining the stages of DNA replication. For a distinction grade, you must evaluate the contribution of chromosomal structure to the inheritance of characteristics.	Presentation.
P5	Monohybrid and Dihybrid Inheritance	Using given parental genotypes, to construct genetic diagrams to the F2 generation, making comments on the predicted phenotypic and genotypic ratios in both monohybrid and dihybrid examples. You also need to explain the difference between observed and expected phenotypes.	Short-answer test.
P4, M1	Inheritance and Variation	Write an illustrated essay detailing the behaviour of chromosomes at each phase of meiosis and the effect on genetic variation of the gametes formed. For a merit grade, they must continue the discussion to include how the expression of eventual genotypes can be affected by environmental factors, with the use of at least three examples.	Written.
P6, P7, P8, M2	Natural Selection and Evolution	Write an essay outlining how species evolve, describing the effect of mutations in the genetic code on the variation between individuals. You must include the conditions required for the Hardy-Weinberg equilibrium to be maintained, explaining the basis of the Hardy-Weinberg equation. You must then apply this to a given population to illustrate why populations do not remain unchanged through the generations. For a merit grade, you will need to expand on the importance of genetic variation, using given population species where genetic variation is a) low (eg Acinonyx jubatus, the cheetah; and b) high (eg Biston betularia, the peppered moth).	Written.

Criteria covered	Assignment title	Scenario	Assessment method
P9, P10, P11, D2	Genetic manipulation	Compile a project consisting of two or three major sections (an introduction and table of contents should also be included). Section 1 – descriptions of genetic manipulation techniques, including methods, materials and timescales. Section 2 – identification of applications of genetic manipulation – all techniques described in section 1 must correspond with at least one application in section 2. In both sections 1 and 2, comments must be put forward on the advantages and disadvantages of genetic manipulation techniques in terms of both practical limitations of the techniques and commercial, social and ethical issues surrounding techniques and applications. Section 3 (for distinction grade) an evaluation of the impact of advancing technology on potential applications of genetic manipulation.	Written project.

Links to National Occupational Standards, other BTEC units, other BTEC qualifications and other relevant units and qualifications

This unit forms part of the BTEC land-based sector suite. This unit has particular links with:

Level 3
Fundamentals of Science

Essential resources

Learners will need access to laboratory facilities, including all usual glassware, waterbaths, pipettes, microscopes etc. If resources for the incubation of Drosophila are unavailable, then there must be access to virtual genetics simulators. Internet access is essential, as are good library facilities including Level 3 biology textbooks (if not specific genetics textbooks), relevant journals and newspapers.

Kits for DNA extraction and manipulation are readily available. Links to laboratories or other centres that have more expensive pieces of equipment are encouraged if the centre does not have their own.

Employer engagement and vocational contexts

Breeding establishments and biomedical laboratories may provide useful work experience for learners and enable them to relate the theory of inheritance and genetic manipulation to the workplace.

Centres are encouraged to make links with suitable organisations to facilitate placements.

Indicative reading for learners

Textbooks

Adds J, Larkcom E, Miller R, Furness-Smith M (ed) – *Genetics, Evolution and Biodiversity* (Nelson Thornes, 2004) ISBN 9780748774920

Bertorelle G, Bruford M, Hauffe H, Rizzoli A and Vernesi C (eds), Population Genetics for Animal Conservation (Cambridge University Press, 200) ISBN 9780521685375

Carroll S B, Grenier K, Weatherbee S D – *From DNA to Diversity: Molecular Genetics and the Evolution of Animal Design* (Blackwell Publishing Ltd, 2004) ISBN 97814051119504

Dawkins R – *The Extended Phenotype: The Long Reach of the Gene* (Oxford University Press, 1999) ISBN 978019288051 2

Dawkins R – *The Selfish Gene* (Oxford University Press, 2006) ISBN 9780199291151

Hartl D and Jones E W – *Essential Genetics: a Genomics Perspective, Fifth Edition* (Jones and Bartlett Publishers, 2009) ISBN 9780763779931

Lochhead W – *An Introduction to Heredity and Genetics: A Study of the Modern Biological Laws and Theories Relating to Animal and Plant Breeding* (Read Books, 2009) ISBN 9781444602128

Thomas A – *Introducing Genetics: From Mendel to Molecule* (Taylor & Francis Ltd, 2003) ISBN 9780748764402

Williams G – *Advanced Biology for You* (Nelson Thornes, 2000) ISBN 9780748752980

Journals

Annual Review of Genetics

Biological Sciences Review

Biotechnology and Bioengineering

Gene Analysis Techniques

Genetics

Genetics Selection Evolution

Journal of Animal Breeding and Genetics

Journal of Zoological Systematics and Evolutionary Research

Mammalian Genome

New Scientist

Theoretical Population Biology

Websites

www.molecular-plant-biotechnology.info	Biotechnology information resources
www.johnkyrk.com	Cell biology animations by John Kyrk
www.dnatutorial.com	DNA Tutorial
www.dnalc.org/resources	Dolan DNA Learning Center – resources
www.yourgenome.org	Educational resources on genetic research from the Sanger Institute
www.jbpub.com/genetics/essentials4e	Essential Genetics – Jones and Bartlett Biological Sciences
www.survivalrivals.org	Experiments for schools – free kits and online resources (Wellcome Trust)
www.iptv.org/exploremore/ge	Explore More (Iowa Public Television) – Genetic Engineering
www.genengnews.com	Genetic Engineering and Biotechnology News
.genetics-education-partnership.mbt.washington.edu	Genetics Education Partnership
www.hhmi.org/biointeractive/index.html	Howard Hughes Medical Institute – BioInteractive
www.molecularstation.com/science-videos	Molecular Station – science videos and lectures
www.moleculesinmotion.com	Molecules in Motion resources and animations
www.merlot.org/merlot/index.htm	Multimedia Educational Resource for Learning and Online Teaching
www.ncbe.reading.ac.uk	National Centre for Biotechnology Education
www.serendip.brynmawr.edu/sci_edu/waldron	Serendip biology activities
www.sanger.ac.uk	Sanger Institute (scientific resources and links for practical placements)
www.sumanasinc.com	Sumanas, Inc – multimedia resources
www.thenakedscientists.com	The Naked Scientists (science radio, podcasts and practical techniques)
www.learn.genetics.utah.edu	University of Utah Genetic Science Learning Center
www.sciencecourseware.org/vcise	Virtual simulation resources

Delivery of personal, learning and thinking skills (PLTS)

The following table identifies the PLTS opportunities that have been included within the assessment criteria of this unit:

Skill	When learners are ...
Independent enquirers	selecting appropriate information to describe DNA replication and chromosomal structure analysing the value of information and supporting conclusions about variation, natural selection and evolution explaining monohybrid and dihybrid inheritance ratios selecting and using information to investigate genetic manipulation techniques and applications, evaluating their advantages and disadvantages
Creative thinkers	questioning their own and others' assumptions about theories of evolution
Reflective learners	communicating learning about structure and behaviour of genetic material considering relevant ways to present information about natural selection and evolution presenting information about genetic manipulation techniques and applications
Self-managers	organising time and resources to describe DNA structure using and describing genetic manipulation techniques
Effective participators	considering the commercial, social and ethical issues surrounding genetic manipulation.

Although PLTS opportunities are identified within this unit as an inherent part of the assessment criteria, there are further opportunities to develop a range of PLTS through various approaches to teaching and learning.

Skill	When learners are ...
Independent enquirers	carrying out practical genetics investigations
Creative thinkers	asking questions during discussions about inheritance
Reflective learners	assessing their own and their peers' presentations on unit topics
Team workers	carrying out practical genetics investigations
Self-managers	organising time and resources to carry out practical genetics investigations
Effective participators	identifying improvements that could be made to practical techniques, proposing practical ways forward in manageable steps.

Functional Skills – Level 2

Skill	When learners are ...
ICT – Find and select information	
Select and use a variety of sources of information independently for a complex task	using the internet to research information for assignments
Access, search for, select and use ICT-based information and evaluate its fitness for purpose	using the internet to research online databases for texts or journals
ICT – Develop, present and communicate information	
Enter, develop and format information independently to suit its meaning and purpose including: ▪ text and tables ▪ images ▪ numbers ▪ records	producing word processed assignments and pictorial presentations
Bring together information to suit content and purpose	producing word processed assignments and pictorial presentations
Present information in ways that are fit for purpose and audience	producing word processed assignments and pictorial presentations
Mathematics	
Understand routine and non-routine problems in a wide range of familiar and unfamiliar contexts and situations	analysing the results of genetic crosses explaining probabilities in monohybrid and dihybrid inheritance ratio examples applying the Hardy-Weinberg equation to given populations
Identify the situation or problem and the mathematical methods needed to tackle it	analysing the results of genetic crosses explaining probabilities in monohybrid and dihybrid inheritance ratio examples applying the Hardy-Weinberg equation to given populations
Interpret and communicate solutions to practical problems in familiar and unfamiliar routine contexts and situations	analysing the results of genetic crosses explaining probabilities in monohybrid and dihybrid inheritance ratio examples applying the Hardy-Weinberg equation to given populations
Draw conclusions and provide mathematical justifications	analysing the results of genetic crosses explaining probabilities in monohybrid and dihybrid inheritance ratio examples applying the Hardy-Weinberg equation to given populations

Skill	When learners are ...
English	
Speaking and listening – make a range of contributions to discussions and make effective presentations in a wide range of contexts	giving presentations on unit topics
Reading – compare, select, read and understand texts and use them to gather information, ideas, arguments and opinions	carrying out research via books and internet sources to produce assignments
Writing – write documents, including extended writing pieces, communicating information, ideas and opinions, effectively and persuasively	producing written assignments.