Biology

Big idea (age 11-14)
BHL: Heredity and life cycles

What's the big idea?

Each generation of organisms inherits characteristics from the one before, which arise from genetic information stored in the DNA of the genome and are affected by the environment. Organisms grow and develop as they get older; they pass genetic information to their offspring when they reproduce, and the life cycle begins again.

Key concepts

The big idea is developed through a series of **key concepts** at age 11-14, which have been organised into teaching topics as follows:

Topic BHL1
Inheritance and the genome

Key concepts:

- BHL1.1 Heredity and genetic information
- BHL1.2 The structure and function of the genome

Topic BHL2
Changes within an organism's lifetime

Key concepts:

- BHL2.1 Growth
- BHL2.2 Life cycles

Topic BHL3
Reproduction

Key concepts:

- BHL3.1 Sexual reproduction in humans
- BHL3.2 Contraception
- BHL3.3 Sexual and asexual reproduction in flowering plants

The numbering gives some guidance about teaching order based on research evidence on learning pathways and effective sequencing of ideas. However, the teaching order can be tailored for different classes as appropriate.

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Learning progression

The science story associated with the big idea develops from age 5 to age 16, and could be summarised as follows:

Science story at age 5-11

Changes within an organism's lifetime

Plants grow from seeds and bulbs into mature plants, and humans and other animals grow from newborn to adult forms. The human body grows and develops during childhood and adolescence, and changes as adults enter old age.

There are differences in the life cycles of flowering plants and of different groups of animals, including mammals, amphibians, insects and birds.

Reproduction

Reproduction is one of the characteristic life processes of living organisms, in which they produce new individuals of the same kind. Usually offspring vary and are similar but not identical to their parents and one another.

Humans and other animals can reproduce when a female individual and a male individual come together to produce offspring. The offspring of humans and other mammals grow inside the mother until they are developed enough to be born, while the offspring of birds, reptiles and fish grow inside eggs until they are developed enough to hatch.

Flowering plants can reproduce when flowers are pollinated to form fruits containing seeds. The seeds are dispersed, and when the seeds germinate they grow to form new plants.

Science story at age 11-14

Inheritance and the genome

Each generation of organisms inherits characteristics from the one before, which arise from genetic information stored in the genome and are affected by the environment. This can explain the similarities and differences between related individuals and other members of the same species.

The genome is stored in cells, and is made of a chemical substance called DNA. Molecules of DNA have a double helix structure, as first explained by Watson, Crick, Wilkins and Franklin. Very long molecules of DNA form structures called chromosomes, and regions of chromosomes are known as genes. The sequences of chemicals in genes are used by cells as instructions for making proteins. Other regions of the DNA in chromosomes are used as instructions that control how and when genes are used.

The structure and development of an organism is controlled by its genome. The growth, features and functions of an organism are affected by its genome and the environment.

Changes within an organism's lifetime

Plants and animals go through a series of changes during their lifetime, including stages of growth, development and reproduction. Together these life stages can be described as a life cycle, in which reproduction creates a new life and the life cycle begins again. Although there are differences between the life cycles of different organisms, all contain stages of growth, development and reproduction.

Organisms grow by increasing the size and number of their cells. All new cells are made from existing cells by a process of cell division. Organisms develop as their tissues, organs and organ systems become specialised for particular functions.

In humans, changes during puberty prepare the bodies of human females and males to reproduce, including the development of the sex organs and production of gametes, and the development of secondary sex characteristics.

Reproduction

Humans, animals and plants can reproduce by making gametes for sexual reproduction. Each gamete carries half of the genome of the parent.

Female and male humans have reproductive systems that make and release gametes. During sexual reproduction, fertilisation takes place inside the female when the female and male gametes join. Fertilisation is followed by gestation, in which the foetus grows and develops inside the female, and then birth.

Flowers have male and female reproductive structures that enable gametes to be made. Male gametes are contained inside pollen grains, which are carried by the wind or by animals to pollinate flowers. Fertilisation takes place when the female and male gametes join. Fertilisation is followed by the formation of fruits containing seeds, which are dispersed by the wind or by animals. Seeds germinate when conditions are favourable.

Plants can also reproduce asexually by making bulbs, tubers or runners. Asexual reproduction involves only one parent, and creates offspring that are genetically identical to the parent and to one another.

Science story at age 14-16

Inheritance and the genome

The genome is made of one or more chromosomes, which are very long molecules of DNA. DNA is a polymer with a double helix structure in which the monomers are nucleotides. Each nucleotide includes one of four different bases (adenine, thymine, cytosine or guanine).

The sequence of bases in regions of each chromosome called genes are used by the cell as instructions to join together amino acids in particular orders to make proteins. Each set of three bases is the genetic code for an amino acid. The properties of the proteins made depend on which amino acids are present and their order. Genome sequences differ between organisms, but the structure of DNA and the genetic code are common to all organisms.

Some sections of DNA do not code for a protein, but they control whether particular genes are expressed, and therefore whether particular proteins are made.

In the cells of plants and animals, chromosomes occur in pairs. The two chromosomes in a pair each carry the same genes. The two versions of each gene in the pair are called alleles, and can be the same or different. A different version of a gene is a genetic variant. The genotype of an organism is the combination of alleles it has for each gene; the phenotype is the characteristic that results from this combination and interaction with the environment.

The order of bases in DNA can be changed if one or more nucleotides is deleted, inserted or substituted for a different nucleotide; these are mutations, and create genetic variants. If the sequence of bases in a gene is changed by mutation a protein made from it may function differently or not at all, though in some cases the mutation won't have any effect. Mutations in non-gene regions can also affect phenotype by altering gene expression.

During sexual reproduction, each offspring inherits two alleles of each gene; one allele from each gamete. The two alleles can be two copies of the same genetic variant (homozygous) or different variants (heterozygous). An allele can be dominant or recessive, and the combination of alleles determines what effect the gene has.

A human individual's sex is determined by the inheritance of genes located on sex chromosomes; specifically, genes on the Y chromosome trigger the development of testes.

Genetic diagrams such as family trees and Punnett squares can be used to model and predict outcomes of the inheritance of characteristics that are determined by a single gene. However, most characteristics depend on the instructions in multiple genes and other parts of the genome.

Principles of inheritance of (single gene) characteristics were demonstrated in ideas developed by Gregor Mendel, using pea plants. Mendel's work illustrates how scientists develop explanations that account for data they have collected. Our understanding of genetics has developed greatly since Mendel did his work; today, scientists sequence whole genomes to investigate how interacting genetic variants in multiple regions of the genome influence an organism's characteristics.

Comparing the genomes of individuals with and without a disease can help to identify alleles associated with the disease. Once identified, we can test for these alleles in adults, children, foetuses and embryos, to investigate their risk of developing certain diseases. We can also assess the risk of adults passing these alleles to their offspring (including the identification of 'carriers' of recessive alleles). Genetic testing can also help doctors to prescribe the correct drugs to a patient ('personalised medicine'), by testing for alleles that affect how drugs will work in their body.

Another application of gene technology is genetic engineering, in which the genome is modified to change an organism's characteristics. Genetic engineering has been used to introduce characteristics into organisms such as bacteria and plants that are useful to humans.

Gene technology could help us provide for the needs of society by improving healthcare and producing food for the growing population. But with genetic testing we must also consider how the results will be used and by whom, and the risks of false positives/negatives and miscarriage (when sampling amniotic fluid). With genetic engineering there are concerns about the spread of inserted genes to other organisms, the need for long-term studies to check for adverse reactions, and moral concerns about modifying genomes.

Changes within an organism's lifetime

New cells are created by mitosis, a form of cell division, for growth and to replace dead cells. Cell division is part of the cell cycle. During the first phase of the cycle – interphase – the cell grows larger, the numbers of organelles increase, and each chromosome is copied; then during mitosis the chromosome copies separate, the nucleus divides, and the cell divides to produce two new cells that are genetically identical to one another.

Cancer is a non-communicable disease in humans caused by changes in a person's DNA. The changes cause a cell to divide many times by mitosis, which can create a tumour.

A zygote divides by mitosis to form an embryo. All of the cells in an embryo are initially identical and unspecialised; these are embryonic stem cells, and can become specialised to form any type of cell (differentiation) by switching genes off and on. Most cells in a human embryo become specialised after the eight cell stage. However, some (adult stem cells) remain unspecialised and can become specialised later to become many, but not all, types of cells. Stem cells mature due to the interaction of the genome and the environment. Stem cells offer the potential to treat patients by replacing damaged tissues or cells. But the benefits must be weighed against risks and ethical concerns about

the use and destruction of human embryos to collect embryonic stem cells. For these reasons, use of stem cells in research and medicine is subject to government regulation in many countries.

In plants, only cells in meristems undergo mitosis, producing unspecialised cells that can develop into any kind of plant cell.

Plants are able to respond to their environment in different ways, e.g. phototropism in shoots and gravitropism in roots. These responses are controlled and coordinated by a group of plant hormones called auxins, and increase a plant's chances of survival.

Plants can also respond to environmental factors using other hormones. Gibberellins are involved in breaking seed dormancy (germination) in response to water, and bolting (production of flowers in an attempt to reproduce before death) in response to cold or lack of water. Ethene is involved in the ripening of fruit and dropping of leaves. Humans can exploit these responses and others such as triggering rooting in cuttings, by using plant hormones to trigger responses that are advantageous to us.

Reproduction

Gametes are produced by meiosis, a different type of cell division. After interphase (during which the chromosome number has doubled), two meiotic divisions occur. Gametes contain half the number of chromosomes found in body cells (one chromosome from each pair). At fertilisation, maternal and paternal chromosomes pair up, so the zygote has the normal chromosome number.

Sexual reproduction leads to variation in populations due to the random combination of genetic material from female and male gametes. Asexual reproduction leads to populations of genetically identical individuals. The evolution of a population or species is affected by whether the individual organisms reproduce sexually or asexually. Sexual reproduction occurs at a slower rate than asexual reproduction, but provides genetic variation in the offspring.

Hormones play a vital role in enabling sexual reproduction in humans: they regulate the menstrual cycle, including ovulation, in adult females. Without this process, sexual reproduction would not be possible.

A number of hormones interact to control the menstrual cycle, including FSH, oestrogen, LH and progesterone. The menstrual cycle can be controlled artificially by the administration of hormones, often as an oral pill. The hormones prevent ovulation, so can be used as a contraceptive, but they do not decrease the risk of sexual transmission of communicable diseases.

Hormones can also be used to artificially manipulate the menstrual cycle as a treatment in certain cases of female infertility in which follicle development and ovulation do not occur successfully.