Biology> Big idea BHL: Heredity and life cycles > Topic BHL1: Inheritance and the genome

Key concept (age 11-14)
BHL1.2: The structure and function of the genome

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.

How does this key concept develop understanding of the big idea?

This key concept helps to develop the big idea by developing understanding that the structure and function of organisms depends on proteins made by cells using instructions stored in the DNA of the genome.

The conceptual progression starts by checking understanding of what the genome is and where it is stored. It then supports the development of ideas about the structure of DNA in order to enable understanding of the functions of coding and non-coding regions of the genome.

Using the progression toolkit to support student learning

Use diagnostic questions to identify quickly where your students are in their conceptual progression. Then decide how to best focus and sequence your teaching. Use further diagnostic questions and response activities to move student understanding forwards.

Progression toolkit:	
Learning focus	What I am teaching
As students' conceptual understanding progresses they can:	CONCEPTUAL PROGRESSION → Observable learning outcomes to guide my teaching focus
Diagnostic questions	Questions to find out what my students know and understand
Response activities	Activities to move my students' understanding forwards

Progression toolkit: The structure and function of the genome

Learning focus	The structure and function of organisms depends on proteins made by cells using instructions stored in the DNA of the genome.				

As students' conceptual understanding progresses they can:

CONCEPTUAL PROGRESSION →

Recall that all organisms store heritable genetic information in their genome inside cells.	Recognise that the genome is made of a chemical substance called DNA.	Distinguish between the terms DNA, chromosome, gene and genome.	Apply the idea that cells use the information coded in regions of the genome called genes as instructions to make structural and functional proteins.	Apply the idea that cells use the information stored in other regions of the genome to control when genes are used. **B**

Diagnostic questions	The function of the genome	DNA	DNA, chromosomes, genes and genomes	Genes	The other 98%
	Locating the genome				

Response activities	Drawing the genome in body cells		How does it all fit together?	From genes to characteristics	Genome journalist
			Genome numbers game		

Key:

P Prior understanding from earlier stages of learning

B Bridge to later stages of learning

What's the science story?

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.

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.

What does the research say?

There is a very large body of research on the teaching and learning of genetics and heredity in schools. While much of the research is focussed on older students (age 14+), this short review attempts to highlight some useful messages for the teaching of younger students.

Conceptions from everyday experiences and the media

Research indicates that children at age 11 are likely to be familiar with the terms "DNA" and "genes" from their everyday experiences, even though these terms may not have been introduced through formal science education before age 11 (AAAS Project 2061, 2009; Department for Education, 2013). Research has also shown that the media, especially television, can be the major source of information – and misunderstandings – about DNA, genes and heredity for primary school students (Donovan and Venville, 2012). The idea that DNA exists only to help solve crimes is one such misunderstanding that can be introduced or reinforced by television shows that heavily feature the theme of police procedural forensics.

Common misunderstandings about DNA, genes and chromosomes

Various researchers (e.g. Lewis, Leach and Wood-Robinson, 2000; Wood-Robinson, Lewis and Leach, 2000; Lewis and Kattmann, 2004; Donovan and Venville, 2012; Witzig et al., 2013) have reported common misunderstandings about DNA, genes and chromosomes in school children, including that:

- DNA is alive;
- DNA is only found in blood, or only in specific cell types (e.g. in the reproductive system);
- some non-living things (e.g. cars) have DNA, and some living organisms (e.g. plants and bacteria) do not;
- genes and DNA are different entities, and specifically that genes are responsible for family resemblance while DNA makes you unique and identifiable (e.g. if it is discovered at a crime scene);
- genes and characteristics/traits are the same thing (e.g. 'blue eyes' is a gene);
- genes are 'particles' that carry a characteristics/trait;
- the terms 'gene', 'chromosome', 'DNA' and 'genetic information' are synonyms.

Developed by the University of York Science Education Group and the Salters' Institute.

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Children can struggle to explain inheritance because of the need to link together understanding at various interacting levels, including the visible trait/phenotype level (e.g. hair colour), the metaphorical information level (e.g. the 'genetic information' that can affect hair colour), the microscopic/molecular structural level (e.g. regions of the genome in which information that can affect hair colour is encoded), and the environmental level (e.g. environmental factors and lifestyle choices that can affect hair colour) (Lewis and Kattmann, 2004; Duncan and Reiser, 2007).

Lewis (2004) notes that "when gene and characteristic are seen as equivalent there is little intellectual need to consider how a gene might be transformed into the characteristic". It may be helpful to establish early the idea that genes store information that is used as instructions to build structural and functional proteins that affect our characteristics; students will be less likely to conflate genes and traits, and may be more receptive to learning about the mechanisms of gene expression, transcription and translation later in their education (Pavlova and Kreher, 2013).

Research (e.g. Duncan, Castro-Faix and Choi, 2016) has suggested that it may be helpful to develop students' understanding of molecular genetics (the structure and function of DNA) before introducing concepts of Mendelian genetics (Mendel's laws governing the inheritance of genes and associated traits).

The genome

Science education researchers have acknowledged that we live in a genomic era. The genomes of humans and many other organisms have been sequenced, and the study of the functions and importance of genes has broadened to whole genomes. Teaching and learning about inheritance and genetics at school must aim to prepare students to live and work in the genomic era (Stern and Kampourakis, 2017).

Defined simply, the genome is the entire DNA of an organism. Recent estimates suggest that genes ("coding" regions of DNA whose sequences encode the order in which amino acids are joined together to make proteins) make up less than 2% of the DNA in the genome (Pennisi, 2007); up to 80% of the remaining "non-coding" DNA – historically mischaracterised as "junk" – is important in controlling gene expression (how and when genes are used to make proteins). Most heritable traits are affected by multiple regions of coding and non-coding DNA. Genomics involves genome sequencing and analysis of the resulting big data sets (bioinformatics) to help us understand the functions and relationships between multiple regions of the genome. Genomics now underpins work in many fields of biological science, and it generates numerous applications and implications for our everyday lives.

Teaching and learning about the science, technologies and implications of genomics poses challenges at all levels of the school curriculum. Up to the age of 14, a useful approach may be to embed 'pro-genomics' and 'pre-genomics' practices – for example, use of language and concepts that dispose students to thinking about whole genomes rather than just genes, and that represent the first steps on a learning progression that will enable fuller understanding of genomics to be built later (Airey, Moore and Bennett, 2018).

Defining "gene"

Advances in genetics, genomics and molecular biology in the past two decades have caused considerable debate about the definition and of the term "gene". More recently, discussions of the problems with the "gene concept" and their implications for biology education have appeared in the science education research literature (e.g. Meyer, Bomfim and El-Hani, 2013). In brief, the classical molecular gene concept defines a gene as a stretch of DNA that

encodes a functional product, specifically a single protein (polypeptide chain) or RNA molecule. This concept of the gene as a structural, functional and informational unit sits well with the Mendelian idea of heritable 'factors' or 'units' that determine traits, and is still widely taken as fact in school classrooms, textbooks, and public consciousness. However, it has been questioned in light of discoveries such as overlapping and nested genes, the important roles of regions of non-coding DNA in regulating gene expression, and mechanisms such as alternative splicing and mRNA editing that enable one-to-many relationships between a 'gene' and several different products.

It may be appropriate to discuss these discoveries – and the "gene concept" debate itself – with older students, for example from age 16 (Department for Education, 2014). However, care should also be taken when exploring ideas about genes with students at age 11-14, to avoid introducing or reinforcing misunderstandings that will be difficult to overcome later. For example, genes could be described in a way that does not imply that they are discrete segments, units or particles of DNA; the notion of the one-gene-one-protein relationship could be avoided; and a pro-genomic view promoted by exploring the idea that multiple coding and non-coding regions of the genome are important in making proteins that affect the structure and function of organisms.

Guidance notes

This key concept adopts a number of practices in light of the research described above. Specifically:

- Pro-genomics language is used, for example by referring to the *genome* rather than to *genes* when discussing where genetic information is stored; and care is taken not to use the terms "DNA", "genes" and "genome" as synonyms.
- The notion of a "one-gene-to-one-protein" relationship is avoided.
- Genes are described as "regions of the genome" (rather than, for example, discrete parts or sections), to allow scope for students – when they are older – to explore ideas such as that a gene can comprise non-contiguous DNA sequences, and that some genes are overlapping or nested.
- Ideas about the effects of the environment on an organism's characteristics are explored together with the effects of the heritable information stored in the genome, to avoid introducing or reinforcing notions of genetic determinism.

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