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

Key concept (age 11-14)
BHL1.1: Heredity and genetic information

What's the big idea?

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.

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

This key concept helps to develop the big idea by developing understanding that similarities and differences between family members can be explained by the passing of genetic information from one generation to the next and the effects of the interaction of organisms with their environment.

The conceptual progression starts by checking students' understanding of heredity using examples of family resemblance. It then supports the reconciliation of everyday understandings of heredity with the idea that characteristics are affected by genetic information passed from one generation to the next and the interaction of organisms with their environment, in order to develop understanding of how similarities and differences between family members can be explained.

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: Heredity and genetic information

Learning focus	Similarities and differences between family members can be explained by the passing of genetic information from one generation to the next and the effects of the interaction of organisms with their environment.				
As students' conceptual understanding progresses they can:	CONCEPTUAL PROGRESSION →				
	Recall that offspring inherit characteristics from each of their parents. **P**	Recognise that an organism's characteristics are affected by genetic information in cells and by the environment.	Explain that biological characteristics are inherited when genetic information stored in the genome of each parent is passed to offspring.	Use the idea that some characteristics cannot be inherited because they are caused by the environment or have to be learnt.	Apply ideas about heredity and environmental factors to explain the similarities and differences between offspring and their parents and siblings.
Diagnostic questions	Dogs and their puppies	What affects an organism's features?	Baby's eyes	Like mother like daughter	Family resemblance
	Her mother's eyes	Is it genetic?			
Response activities	What will the offspring look like?	Why we look like we do	Inheriting the genome	Can it be inherited?	
			The next generation		

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. This can explain the similarities and differences between related individuals and other members of the same species.

What does the research say?

There is a very large body of research on the teaching and learning of heredity and genetics 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.

Explaining heredity

From their everyday experiences (for example, of families and pets) students at age 11 should be aware that living organisms can reproduce to make offspring of the same kind (species resemblance), and that offspring are usually similar but not identical to their parents (body traits resemblance). These ideas are likely to have been formalised through science education before age 11 (AAAS Project 2061, 2009; Department for Education, 2013). Nevertheless, research reported by a number of authors (e.g. Driver et al., 1994; Williams, 2012; Cisterna, Williams and Merritt, 2013; Allen, 2014; Ergazaki et al., 2015) suggests that children up to age 11 have numerous misunderstandings about family resemblance and how characteristics are passed from one generation to the next, including that:

- all characteristics are inherited from an organism's mother – perhaps because the mother carries the child and gives birth;
- girls inherit most or all of their characteristics from their mother, and boys from their father;
- the intentions or desires of the parents can influence the characteristics of their offspring (e.g. wanting a girl with blue eyes);
- similarities between siblings are all due to "nurture" (e.g. because siblings are brought up together, or because they copy one another);
- differences between offspring and their parents must be due to adoption, "surprise", or inheritance from grandparents (the randomness of genetic inheritance and environmental factors were not often cited as reasons for differences)
- acquired characteristics (resulting from interaction with the environment or from learning) can be passed from parents to offspring.

Lewis (2004) and others have argued that "students' everyday conceptions and alternative frameworks are an essential starting point from which scientific understanding can be developed", and in the context of inheritance she suggests "beginning the teaching with discussion of observed phenomena relating to heredity [to] provide opportunities for students to articulate their everyday experiences and conceptions [from which] teachers could begin to elucidate conceptions of genes".

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 that can affect hair colour) (Lewis and Kattmann, 2004; Duncan and Reiser, 2007).

Several studies have suggested introducing explanations of heredity to children using, initially, a very simplified idea of genetic material to serve as a 'conceptual placeholder' or 'conceptual peg'. This can help children to "hold in place" a rudimentary scientific explanation upon which more detailed explanations of what is inherited and how can be built later (Solomon and Johnson, 2000; Ergazaki et al., 2015).

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). A very simple example may be referring to "your genome" rather than "your genes" when discussing where genetic information is stored and what is inherited.

Genetic determinism

Most of an organism's characteristics are affected by multiple genes, by non-coding regions that affect gene expression, and by the organism's lifestyle and environment (Forissier and Clément, 2003). However, research indicates that most students at secondary school level think of genes as the only determinants of an organism's characteristics – a conception dubbed 'genetic determinism' (Jamieson and Radick, 2017; Stern and Kampourakis, 2017). Genetic determinism can underlie (or be used to justify) dangerous assumptions and prejudices, such as that individuals are limited by their genes, and that all traits and behaviours are innate and cannot be changed. Teaching from an early stage about the difference between inherited and acquired characteristics, and the role of environmental factors in shaping an organism's characteristics, can help to reduce notions of genetic determinism.

Guidance notes

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

- Explanations of family resemblance based on naïve, everyday understandings of heredity are reconciled with the idea that characteristics are inherited when genetic information is passed from one generation to the next.

- Genetic information is explained as being stored in the genome (making the link between metaphorical 'information' and a heritable cellular structure), wherein "the genome" serves as a 'conceptual placeholder'. Details of what the genome actually is are developed in the following key concept, BHL1.2 *The structure and function of the genome*.
- Pro-genomics language is used, for example by referring to the *genome* rather than to *genes* when discussing where genetic information is stored and what is inherited.
- Ideas about acquired characteristics and 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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