*Biology > Big idea BVE: Variation, adaptation and evolution > Topic BVE3: Evolution*

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| **Key concept (age 11-14)** |
| **BVE3.1: Explaining evolution** |

**What’s the big idea?**

A big idea in biology is that the great diversity of organisms, living and extinct, is the result of an ongoing process of evolution by natural selection.

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

This key concept helps to develop the big idea by exploring natural selection as an explanation for why the characteristics of species change over generations.

The conceptual progression starts by checking awareness of the evidence provided by fossils that the features of species change over time, and understanding of the idea that only genetic variation can be inherited. It then supports the development of understanding of how competition, fitness and natural selection can lead to evolution by causing advantageous traits to become more common in a population over a number of generations.

**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: Explaining evolution**

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| **Learning focus** | The characteristics of a species can change over generations as advantageous adaptations become more common; this is evolution, and can be explained by a process of natural selection. | | | | |
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| **As students’ conceptual understanding progresses they can:** | **C o n c e p t u a l p r o g r e s s I o n** | | | | |
| Explain how the fossil record provides evidence that species change over time.  **P** | Recognise that there is variation between individuals within a species, and that only genetic variation can be inherited. | Recognise that organisms compete for limited resources, and that some individuals have traits that help them compete more successfully than other individuals in the same population. | Use ideas about heritable variation, competition, fitness and natural selection to explain why an advantageous trait became more common in a population over a number of generations. | Apply the idea that evolution by natural selection occurs within populations, over generations and without foresight. |
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| **Diagnostic questions** | What can we learn from fossils? | Variation | Penguin population | The changing faces of evolution | Is it evolution? |
| The fossil record | Heritable variation? | Forest dwellers | Silence on the island |
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| **Response**  **activities** |  | Observing and explaining variation | The struggle for existence | Evolution in the garden | |
|  | Can it be inherited? |

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| Key: | | | |
| **P** | Prior understanding from earlier stages of learning | **B** | Bridge to later stages of learning |

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| **What can we learn from fossils?** | **The fossil record** | **Variation** | **Heritable variation?** | **Penguin population** |
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| Confidence grid | Linking ideas | Two-tier multiple choice | Two-tier multiple choice | Simple multiple choice |
| **Forest dwellers** | **The changing faces of evolution** | **Is it evolution?** | **Silence on the island** |  |
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| Two-tier multiple choice | Simple multiple choice | Confidence grid | Talking heads |  |

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| **Observing and explaining variation** | **Can it be inherited?** | **The struggle for existence** | **Evolution in the garden** |  |
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| Challenge to thinking,  discussion | Discussion | Concept map, discussion | Discussion |  |

**What’s the science story?**

The fossil record provides evidence that the characteristics of species change over time, and that many species that once existed are now extinct.

There is variation between individual organisms of the same species, which can be caused by differences in their genomes, lifestyles and their interactions with their environment. Only variation caused by differences in the genome can be inherited. There is competition between individuals of the same species for limited resources that are essential for survival. Variation between individuals means that some individuals are better adapted to compete, and some are less well adapted. Individuals that are better adapted are more likely to survive to reproduce, and may pass on their advantageous characteristics to their offspring. This process of natural selection can cause the common characteristics of a species to change, and thus the species to evolve, over a number of generations.

**What does the research say?**

A large body of research into teaching and learning about evolution has developed since the mid-1990s from a relative dearth prior to that (Cummins, Demastes and Hafner, 1994); useful reviews are provided by Gregory (2009) and Smith (2010). The research indicates that natural selection and evolution are generally very poorly understood by students and by members of the wider public (Gregory, 2009). It is beyond the scope of these teacher notes to provide a comprehensive overview of such a large body of research, but some key themes from the research are summarised on the following pages.

*Not “just a theory”*

Famously, the evolutionary biologist Theodosius Dobzhansky asserted that “nothing in biology makes sense except in the light of evolution” (Dobzhansky, 1973). The theory of evolution by natural selection is regarded as a unifying concept in biology, providing a persuasive explanation for how the amazing biodiversity of the Earth has arisen and continues to change through subsequent generations due to natural selection.

The characteristics of species change over generations. This process is called evolution and is not theoretical; there is ample evidence that it takes place. Some of this evidence includes fossils that have similarities to, and differences from, extant species, and which can be observed in the classroom and during fieldwork to build understanding and increase engagement (Hunter et al., 2018). The theory of evolution by natural selection is a scientific explanation for how and why species evolve, and is widely accepted by the scientific community because it is well supported by evidence.

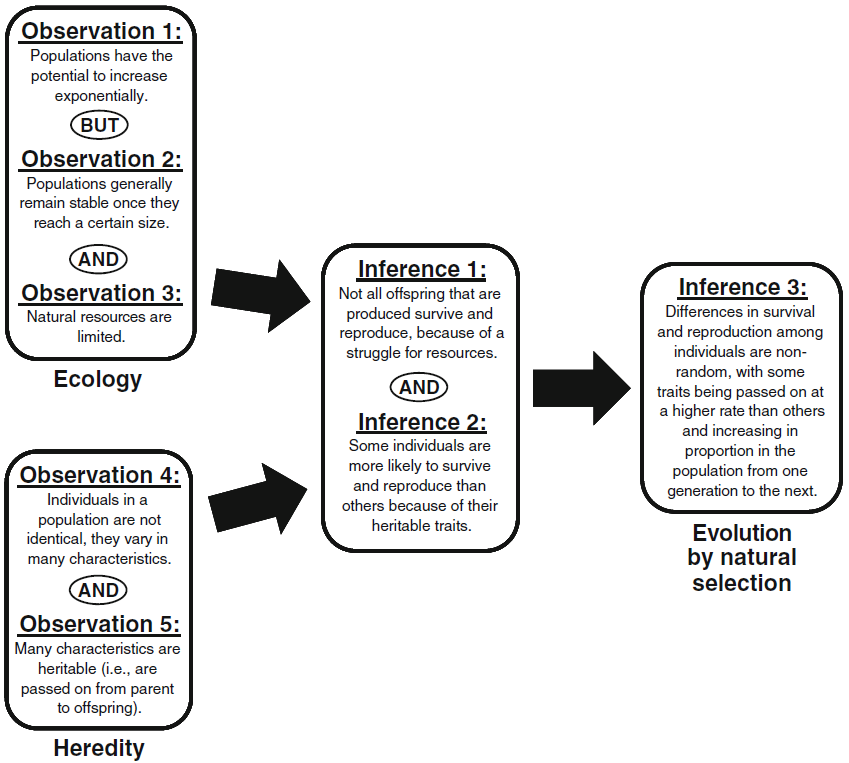
The common practice of abbreviating the phrase “the theory of evolution by natural selection” to the shorter phrase “the theory of evolution” could create or reinforce the misunderstanding that evolution itself is theoretical, which it is not; evolution – changes in the heritable characteristics of species over successive generations – incontrovertibly takes place. The scientific theory is that natural selection is a key mechanism by which the evolution of species takes place. The term “theory” is often used and understood in classrooms in ways that do not match the scientific use and meaning of the term (Gregory, 2008; Williams, 2013). In everyday language, the term “theory” is often used to refer to something that is little more than a guess or hunch, lacks supporting evidence and is unproven or untested. In contrast, a scientific theory is a general explanation that applies to a large number of situations or examples (perhaps to all possible ones) that is widely accepted because it has been extensively tested and evidenced.

For some students, perhaps particularly those with literalist religious beliefs, learning about evolution in biology lessons may leave them feeling conflicted if the scientific explanations for evolution that they are presented with do not agree with ideas they have encountered elsewhere. It has been suggested that evolution should be treated as a sensitive issue rather than a controversial one (Reiss, 2019), and that students’ worldviews should be accommodated respectfully. Rather than setting out to replace their current worldviews, a useful aim of biology lessons is to help students to appreciate how the scientific explanation of evolution by natural selection was developed from evidence, and why the great majority of scientists (including many with religious beliefs) therefore accept it as a robust explanation based on the available evidence (Graham and Moore, 2021).

*Evolution by natural selection*

Fossils and other evidence show that the characteristics of species change over generations, and this change is called evolution. Biologists explain evolution by combining ideas about heritable variation, competition, fitness and natural selection to explain why advantageous traits become more common in populations over generations.

The explanation for evolution developed by Charles Darwin, Alfred Russel Wallace and others, and described by Darwin in his book *On the Origin of Species by Means of Natural Selection* in 1859, have been summarised by Mayr (1982) and others into five observations (or facts) and three inferences – see Figure 1.



**Figure 1:** A summary of Darwin’s theory of evolution by natural selection; adapted from Mayr (1982) and Gregory (2009).

**Ecology**

**Heredity and variation**

**Competition and natural selection**

**Evolution**

According to Smith (2010), this summary has stood the test of time; aspects about which Darwin could only speculate – including the source of variation and the mechanisms of inheritance – have been expanded and fleshed out with evidence and understanding over the last century and a half.

Science education researchers have created a series of diagnostic questions called the ‘conceptual inventory of natural selection’ (CINS) designed to assess understanding of the five observations and three inferences as well as modern understanding of the genetics of variation and inheritance (Anderson, Fisher and Norman, 2002). Although the CINS questions are designed for undergraduate students, they have provided inspiration for diagnostic questions developed for BEST.

Gregory (2009) notes that our modern understanding of the process of evolution by natural selection comprises both random and non-random aspects, and describes a two-stage model of the process; a version that could form the basis of understanding at age 16 (and for which the foundations could be laid during teaching at age 11-14) is as follows:

1. Random variation – which arises due to mutations and recombination of alleles during sexual reproduction, both of which are random (non-directed and non-intentional). Most new variations have a neutral effect on competition, some are harmful, and some are advantageous.
2. Non-random selection – in which, due to competition and natural selection, individuals with advantageous variations are more likely to survive to pass their heritable variations to their offspring.

Both stages occur in every generation, and may be thought of as the *source* and *sorting* of variation, respectively. Over multiple generations, this has the effect of increasing the proportion of advantageous heritable variations present in the population – this is the process by which a population becomes better suited to its environment (adaptation), and can lead to the evolution of species. Natural selection does not *create* variation (a common misunderstanding), but over a number of generations it influences the proportion of individuals within a population that inherit particular variations.

So, what are the key ideas that biology lessons at age 11-16 could aim to establish and draw together to help students to understand the scientific explanations for evolution? To help develop understanding and provide a foundation for further learning, at least the following ideas should be explored (Anderson et al., 2002; Smith, 2010; Graham and Moore, 2021):

* **Variation:** there are differences between individuals within a species, and some of these differences can be inherited.
* **Competition:** limited resources and over-production of offspring means organisms compete with one another to survive.
* **Fitness and natural selection:** some individuals have features that give them an advantage in competition, and therefore a better chance of surviving to reproduce, especially when environmental conditions change; these individuals are therefore more likely to pass on heritable features – some of which are advantageous – to the next generation.

At age 11-14, these key ideas can be explored at trait (phenotype) level. By age 16, more-able students should be able to explain the causes of variation and the effects of natural selection at the genetic level, including the ideas that variation arises from random mutations and from random recombination of alleles during sexual reproduction, and that alleles associated with advantageous traits become more common in populations over generations due to natural selection, which can lead to speciation.

*Common ways of thinking that lead to misunderstandings (and impede the development of scientific understanding)*

Many researchers have described common misunderstandings about natural selection and evolution, which are present and persistent in students from school age up to university level (Evans, 2008; Gregory, 2009). Many of these misunderstandings arise from naïve, everyday ways of thinking that – whilst intuitive and therefore difficult to overcome – do not align with the accepted scientific explanations for evolution by natural selection that students encounter in science lessons (Gregory, 2009; Smith, 2010). These naïve ways of thinking can be classified into broad categories (Coley and Tanner, 2012; Newall, 2015), including:

**Essentialism:** This is the incorrect belief that each species has a uniform ‘type’ or a common ‘essence’ and that variation among individual members of a species is an anomalous or unimportant deviation from this norm. Research indicates that it is common for students to believe that while there are differences *between* species there is no variation between individuals of the *same* species (Shtulman, 2006; Gregory, 2009), and numerous studies have found that when students of various ages were asked to explain evolution by natural selection, very few students explicitly included ideas about variation within species (Gregory, 2009). Lack of understanding of variation could be related to some other commonly observed misunderstandings, such as that the environment or natural selection cause heritable variations (Alters and Nelson, 2002; Andersson and Wallin, 2006), that drastic environmental change is required for evolution to occur (Nehm and Reilly, 2007), and that the whole species or population changes at once (e.g. from one generation to the next one, rather than gradually over many generations) when adaptation/evolution occur (Shtulman, 2006).

**Lamarckism / ‘soft inheritance’:** This is the incorrect belief in the inheritance of acquired characteristics, whereby evolution proceeds because organisms pass on characteristics they have acquired through use or disuse during their lifetime (Engel Clough and Wood-Robinson, 1985; Alters and Nelson, 2002). Research reported by a number of authors suggests that children up to age 11 have numerous misunderstandings about the inheritance of characteristics from one generation to the next, including that acquired characteristics (e.g. variation resulting from interaction with the environment) can be passed from parents to offspring (Cisterna, Williams and Merritt, 2013). Examples such as a weightlifter’s muscles or even something as simple as a scar can be used to probe and challenge students’ Lamarckian ideas. A similar and common misunderstanding is that changes within an individual’s lifetime constitute adaptation or evolution (Alters and Nelson, 2002) – they do not; adaptation and evolution refer to the process of accumulation of advantageous traits in a population over generations (Andersson and Wallin, 2006).

**Teleology and anthropomorphism:** Teleology is incorrectly ascribing a goal, intention or purpose to a natural process. In the case of evolution by natural selection, it is common and intuitive – but incorrect – for students to think and use language that implies that adaptations arise by design or in order to fulfil a need (Alters and Nelson, 2002; Kelemen, 2012). This way of thinking may also be associated with anthropomorphism, in which human emotions and motivations are incorrectly evoked to explain a phenomenon (Tamir and Zohar, 1991), for example in assuming that organisms want or choose to adapt and evolve (Legare, Lane and Evans, 2013).

**Views about how evolution applies to humans and other organisms:** Students may incorrectly think that the present form of a species (particularly humans) is the final or perfect form, suggesting that the evolution of that species has finished; this misunderstanding may arise from the perception of evolution as a series of discrete events within the context of a specific (often historical) example ( e.g. finches’ beaks or horse skeletons), rather than as a dynamic ongoing process (Evans, 2008; Sinatra, Brem and Evans, 2008). Students may believe that while animals need to evolve to survive, plants do not (Bizzo, 1994), or that humans have some special status separate from the animal kingdom and are not subject to evolution by natural selection (Newall, 2015).

In addition to these naïve ways of thinking, evolution-related terminology can also be associated with misunderstandings. Terms such as “evolution”, “fitness” and “adaptation” are used in everyday life in ways that do not reflect the scientific usage, and can confuse students if they are used in teaching without careful explanation (Andersson and Wallin, 2006). The phrase “survival of the fittest” is often used without (or in order to avoid having to demonstrate) understanding of the mechanisms involved, and many students incorrectly think “fittest” refers to the most athletic or strongest individuals rather than to the individuals best adapted to compete and survive to reproduce in their environment (Gregory, 2009).

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