

The understanding of evolution at primary school: can an intervention
improve conceptual understanding?



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Abstract

The study aimed to describe the understanding of evolution of 10-11 year olds at primary schools in England and investigated whether their understanding can be improved when they are exposed to instruction. Evolution is a unifying concept in biology and although existing literature indicated that evolution is poorly understood by many adults, including teachers and children at secondary school, it was recently introduced in the English National Curriculum for primary school. Research is needed to clarify to what extent it is possible to improve primary school children's understanding of this complex concept. There is very limited research with primary school children, so it is unclear whether the inclusion of evolution provides primary school teachers with a realistic aim or whether challenges will arise from its inclusion in the National Curriculum.

In order to analyse the impact of instruction on the understanding of evolution, a teaching intervention was designed using the principles of Cognitive Acceleration through Science Education (CASE). CASE aims to promote cognitive development as well as the understanding of science concepts; in this study, the CASE framework was implemented in the study of evolution. The intervention focussed on six concepts hypothesised to be core elements of the concept of evolution; variation, inheritance, adaptation, domestication, speciation and extinction.

The impact of the intervention was evaluated using an experimental design, which included a pre- and post-test and the random assignment of pupils to the intervention or the control groups. At pre- and post-test, pupils completed an assessment of cognitive development as well as an assessment that covered the six core elements involved in understanding evolution. The participants were 114 Year 6 (10-11 years old) children from two primary schools in England. They were randomly allocated to one of three groups: evolution intervention, an active control group who participated in an intervention about electricity or an unseen control group. The electricity intervention was also designed according to the principles of CASE. The unseen control group received no instruction.

It was predicted that: (1) the evolution group would perform better than the two other groups in the assessment of understanding of evolution; (2) both the evolution and the electricity group would perform better than the unseen control group in an assessment of cognitive

development. Analyses of covariance showed that the evolution group performed significantly better than the unseen and electricity control groups in their understanding of evolution as measured by the assessment of the six core concepts. The quality of written justifications and the frequency of technical vocabulary used correctly in the assessment significantly increased for the evolution group when compared to the other two groups. There was no difference between the groups on the measure of cognitive development.

This study makes several methodological and empirical contributions to knowledge: a fully piloted assessment tool appropriate for children aged 10-11, a detailed study of children's understanding of evolution and a rigorously evaluated teaching intervention designed for this age group which has educational implications for curriculum design, resources and teacher training. In addition the study makes theoretical contributions with regards to the conceptual understanding of evolution of 10-11 year olds by detailing which concepts are harder to understand than others.

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Chapter 1: Introduction

1.1. Aims of the study

The current study aimed to describe the understanding of evolution and to examine the impact of a teaching intervention on the understanding of evolution of 10-11 year olds at primary school in England. The study involved the development of an instrument to assess the understanding of children as well as the design, the implementation and the evaluation of the impact of the teaching intervention.

Evolution is a unifying concept in biological science, in the sense that understanding many other concepts are facilitated by a secure understanding of evolution. In spite of its importance, evolution is widely misunderstood and misconceptions have been evidenced in primary school children (Berti, Toneatti and Rosati, 2010), middle and secondary school children (Beardsley, 2004; Settlage, 1994), biology undergraduates (Shtulman, 2006), teachers (Deniz, Donnelly and Yilmaz, 2008) and other adult populations including museum visitors (Evans, Spiegel, Gram, Frazier, Tare, Thompson and Diamond, 2010). Evolution attracts controversy and media attention especially when discussed within an educational context (Rosengren, Brem, Evans and Sinatra, 2012) primarily because of the perceived conflict with religious beliefs.

Although the understanding of evolution seems to be a challenge even for students at the university level, it was introduced in the curriculum in primary schools in England in 2013 (National Curriculum in England, 2013). The inclusion of evolution in the primary school curriculum could be seen as a brave step forward to promote the understanding of this very

important concept in modern science. It is possible that, if we start to promote thinking about evolution in primary school, by the time this cohort of children reaches secondary school, they will be better prepared to understand evolution, even if the concept eludes them to some extent at the time they first encounter it in primary school. But it is also possible that it is a foolhardy move, if the concept is beyond the pupils' cognitive ability and too complex for them. The time teaching evolution in primary school would be wasted and could have been better used teaching another scientific concept, one which is more likely to be within their grasp.

Presently, there is a lack of empirical research on primary-aged children's understanding of evolution, and on how to teach this complex topic to younger children, and the proposed study will start to address the significant lack of literature in the UK, by examining the current levels of conceptual understanding among primary school children and by analysing the efficacy of one teaching approach that aims to improve the pupils' understanding of evolution. The challenges faced in the design and implementation of the current study were twofold.

First, intervention research is the preeminent design to evaluate the teachability of a concept. A survey design to establish the understanding of evolution amongst primary school pupils in England would provide information on what pupils grasp about the concept, but without knowing the impact of teaching, as the topic has not yet been taught in primary schools. Arguably, a longitudinal design could be used to compare pupils' knowledge before and after the introduction of the topic in the curriculum. However, teaching could vary across schools and could be based on different approaches, so the interpretation of such comparisons would be ambiguous. An intervention study that showed

a positive impact of teaching would be much more convincing. However, if the intervention study failed to show the impact of teaching on pupils' understanding of evolution, the interpretation of this negative result would not be straightforward. The failure to obtain an impact could be attributed, for example, to a poor design of the intervention or to the insufficient amount of time dedicated to the teaching or both. A better intervention or one that used more time might have shown that it was possible to have a significant impact on the pupils' understanding.

The second challenge originates in the lack of research on primary school children's understanding of evolution. This means that there are no instruments that could be used to analyse the impact of the intervention and no baseline level about their understanding of the concept. The intervention could be pitched at a level too high or too low for the pupils and the assessment used might not be a valid one.

In spite of these challenges, the choice of an intervention design was made in the current study in view of the strength of the evidence it could produce: if an intervention could be shown to have a positive impact on the pupils' understanding, it would produce strong evidence for the inclusion of the topic in primary school. Because evolution is considered one of the important scientific concepts that impacts the way people understand the world around them, its inclusion in the Primary National Curriculum would (seek to) guarantee that all pupils had some exposure to the concept, whether or not they continue to study science after primary school.

The remainder of this chapter will present the contextual background for the study including details of the curriculum changes. Evolution will be defined and the conceptual

understanding described before a discussion about the acceptance of evolution. Finally the proposed structure of the thesis will be described and a summary of the chapter contents will be given.

1.2. What is evolution?

Evolution is a central theme in biology and provides a framework for many other scientific ideas. The origin of species has been hypothesised about for thousands of years before the theory was formalised by Charles Darwin during the 19th century despite a lack of genetic knowledge. The theory has continued to develop in recent decades as genetic discoveries continue and is widely accepted by the scientific community.

Evolution is a broad, well-tested description of how Earth's present-day life forms arose from common ancestors reaching back to the simplest one-celled organisms almost 4 billion years ago. It helps explain both the similarities and the differences in the enormous number of living organisms we see around us. (American Association for the Advancement of Science, 2006 p22).

Our current scientific understanding of evolution is known as the *Modern Evolutionary Synthesis*, a term proposed by Julian Huxley (1942) to describe the synthesis of Darwinian ideas published in *The Origin of Species* (Darwin, 1859) and the more recently discovered genetic concepts. The complexity of evolutionary theory makes it necessary to identify the introductory level concepts to be addressed during science education at school if a secure understanding of evolution is to be achieved.

Ernst Mayr, a leading evolutionary biologist in the 20th century, proposed that evolution was a set of 5 facts and 3 inferences (Mayr, 1982 p479-480).

Fact 1 – All populations have the potential to grow at an exponential rate.

Fact 2 – Most populations reach a certain size, and then remain fairly stable over time.

Fact 3 – Natural resources are limited.

Inference 1: Not all offspring survive to reproductive age in part because of competition for natural resources.

Fact 4 – Individuals in a population are not identical, but vary in many characteristics.

Fact 5 – Many of the characteristics are inherited.

Inference 2: Survival is not random. Those individuals with characteristics that provide them with some advantage over others in that particular environmental situation will survive to reproduce, others will not.

Inference 3: Populations change over time as the frequency of advantageous alleles increases. These could accumulate over time to result in speciation.

Several authors have proposed different groups of concepts which are simplified and deemed more appropriate for school-age teaching (Passmore and Stewart, 2002; Biological Sciences Curriculum Study, 2005; Andersson and Wallin, 2006; Catley, 2006; Shtulman, 2006) and are compiled into the following list:

- 1) Role of within-species variation
- 2) Heritability of variation (inheritance)
- 3) Accumulation of changes over many generations (adaptation)
- 4) Differential survival and reproduction
- 5) Competition for limited resources
- 6) Species evolve over time
- 7) New species form from existing species (speciation)
- 8) Extinction

The concepts in this list can be grouped in two categories: those related to micro-evolutionary concepts (statements 1-5) and those related to macro evolutionary concepts

(statements 5-8). Micro-evolution is concerned with variation and adaptation that occur at the within-species level whereas macro-evolution is the divergence of species (speciation) and any changes happening above the species-level such as extinction (Reznick and Ricklefs, 2009). Catley (2006) argues that current evolutionary teaching mainly focuses on micro-evolutionary concepts and macro-evolutionary concepts are often omitted, yet must be considered when designing curriculum.

Evolution as a scientific theory is very complex and it is highly unlikely that primary school children will be able to understand it fully. However, children's understanding of any complex concept does not happen in an 'all-or-nothing' fashion, and it is often the case that if they are taught about a complex concept they master some aspects earlier than others (e.g. children understand informally some aspects of proportionality when they are about 5 or 6 but other aspects seem to be mastered only through teaching at about age 12/13; Nunes and Bryant, 2015).

Currently, it is unknown which of the concepts listed above primary-aged children can understand, as there is an absence of empirical research with this age group. Likewise, there is very little research addressing which of the concepts listed above are more difficult for primary-aged children and which are easier; research is required also to determine which concepts are necessary steps towards learning the others (Smith, 2010). This study contributes knowledge about the conceptual understanding of primary school children as describes the understanding of different concepts of children at primary school.

1.3. Why is it important to understand evolution?

There are two key arguments as to why it is important to understand evolution. Firstly evolution is considered a unifying concept in biology and aids the understanding of many other topics. Secondly it contributes to scientific literacy which allows citizens to make well-reasoned decisions about wider global issues such as climate change, antibiotic resistance or a reduction in biodiversity.

1.3.1. A big idea

‘Nothing in biology makes sense except in the light of evolution’ was the title of an essay written by Dobzhansky (1973) and is a statement reaffirmed by many biologists since including Gould (1999, p59), who said ‘Evolution is not a peripheral subject but the central organizing principle of all biological science’. Many research articles and books about evolution education open by stating that evolution is a unifying, central or very important concept within science (Beardsley, 2004; Gregory and Ellis, 2009; Harms and Reiss, 2019; Sanders and Ngxola, 2009; Shtulman and Checa, 2012; Wagler, 2010; Zook, 1995).

Its importance as a concept has led evolution to be included in many curricula in many countries and is acknowledged by large organisations that have great influence on science education. In 1996, The National Academy of Sciences in the US said that evolution should be taught in every school grade starting in Kindergarten (ages 4-6) as it is one of the five unifying concepts and processes (National Research Council, 1996) and they go on to say ‘to teach biology without explaining evolution deprives students of a powerful concept that

brings great order and coherence to our understanding of life' (National Research Council, 1998 p3).

Motivated by the lack of coherence across primary and secondary science education an international seminar was held in 2008 to identify the *10 big ideas of science* which should be taught throughout school rather than as succinct topics. The report compiled as a result of the seminar (Harlen, 2010) identified evolution as one of the *10 big ideas of science*. It was deemed essential for young people to understand if they are to comprehend the world around them scientifically.

The diversity of organisms, living and extinct, is the result of evolution

A single-celled organism was the first life on Earth and is the common ancestor of all life that has existed. Variation within species has allowed individuals most suited for survival to be selected for and over many generations adapt to environmental pressures. Species that do not respond quickly enough face extinction. (Harlen, 2010 p22)

The central argument within the *10 big ideas of science* report is that the ideas are accumulative and should be taught throughout the science curriculum within the context and at the level that is cognitively appropriate. The report details how the big ideas can be built from small ideas over time and provides suggestions for how this might work for evolution.

Despite its scientific prominence, whether evolution is taught to primary-aged children in each country is determined by the relevant curricula, often written by the government.

Whilst it is included in the education documentation in many places it is not included for all countries or regions within countries.

1.3.2. Scientific literacy

A working understanding of evolution is a critical component of scientific literacy and has been deemed necessary by several countries in scientific reform reports (Smith, 2010).

Scientific literacy is the ability to engage with science-related issues, and the ideas of science, as a reflective citizen. A scientifically literate person is willing to engage in reasoned discourses about science and technology, which requires the competencies to:

- Explain phenomena scientifically – recognise, offer and evaluate explanations for a range of natural and technological phenomena
- Evaluate and design scientific enquiry – describe and appraise scientific investigations and proposes ways of addressing questions scientifically
- Interpret data and evidence scientifically – analyse and evaluate data, claims and arguments in a variety of representations and draw appropriate scientific conclusions (OECD, 2017 p22)

Young adults should be able to evaluate claims in support or against evolution when provided with evidence and make informed decisions with consideration of any ethical or moral concerns. These are arguably life skills that benefit individuals on a scale much greater than the learning of evolution itself. It has been suggested that the exclusion of evolution from the curriculum could even be considered educational malpractice (Smith, 2010) as it would be a failure by any government to create citizens that can make a positive contribution to society.

It might seem that the concept of evolution has no relevance to making informed decisions at the present time: what happened in the past is not going to change where we are now.

However, as argued by Catley (2006), evolution education plays an important role within the context of understanding the importance of biodiversity: given the rapid destruction of biodiversity by human activity there is an educational need to nurture ‘a stewardship ethic for a planet moving ever deeper toward ecological collapse’ (p781) and evolution is the basis for this ethic.

A secure understanding of evolution may, on some occasions, allow individuals in positions of influence to make better informed decisions about biodiversity and the environment which is important because maintaining high levels of biodiversity is of benefit to the human population. Nearly half of pharmaceutical medicines have naturally sourced chemicals as a key ingredient and many more have synthetic chemicals based on naturally occurring compounds (Tulp and Bohlin, 2002). A reduction in biodiversity would lessen the potential to discover new medical drugs which is critically important as bacteria become increasingly resistant to antibiotics. Researchers are using evolutionary ideas such as selection and the fitness of individuals to attempt to slow the rapid appearance of antibiotic resistant bacteria (Andersson and Hughes, 2010). At a high-level general assembly meeting in 2016 the UN recognised drug-resistant infections as one of the greatest threats to humanity reinforcing the importance of plans set in place by the World Health Organisation the previous year. Widespread bacterial resistance poses a great threat to human mortality because antibiotics are used globally as a medical intervention to reduce infection, especially in vulnerable populations such as the elderly or the infirm.

A report commissioned by the UK government (UK Commission for Employment and Skills, 2015) acknowledges that STEM (science, technology, engineering and maths) graduate jobs are twice as hard to fill (43%) compared to the national average of 24%;

biotechnology (for which biodiversity and genetic technology play a major role) is identified in the report as a key employment area. Increasing STEM graduates in the UK is said to be necessary ‘to reshape its economy around high value’ (p5). The Biotechnology and Biological Sciences Research Council (BBSRC, 2017) highlight the sector growth within the UK, which is the leading country within the EU for research and funding, with the industry supporting 5.2 million jobs (981,000 directly) and adding £220 billion to the economy annually.

The uptake of STEM courses at university level is influenced by science education during compulsory schooling and the topics to be taught are determined by the National Curriculum. The addition of evolution to the Primary National Curriculum for Science for teaching from September 2014 (National Curriculum in England, 2013) means the topic may have an influence on pupils that later choose STEM subjects.

1.4. Conceptual understanding of evolution

There is a growing body of research that shows that many adults hold some incorrect conceptions of evolution (Shtulman, 2006; Gregory and Ellis, 2009; Evans, Spiegel, Gram, Frazier, Tare, Thompson and Diamond, 2010; Shtulman and Calabi, 2013). The most common misconceptions are described by Gregory (2009) as:

- That the use of a trait is the cause of its growth in an individual which is then inherited by offspring.
- That new traits appear because they are necessary for survival rather than by random mutation.
- That all members of a population change to suit the environment rather than differential survival and differential reproduction.

- That individuals deliberately change to suit their environment and these intentional changes are inherited by offspring.

Mayr (2001) proposed that, in the analysis of how people understand evolution, two opposing conceptions can be identified, termed *variational* and *transformational*. These opposing conceptions are defined by a cluster of ways of thinking about the different core concepts that are crucial to understanding evolution. The prevalence of misconceptions evidenced in the literature makes it seem unlikely that simply learning the facts and inferences stated by Mayr (1982) will lead to a secure understanding of evolution by primary school children; it is more likely that a significant restructuring of thinking is required (Vosniadou, 2013). When a substantial revision of existing knowledge is required to acquire new conceptual knowledge the process of learning is called conceptual change (Duit and Treagust, 2003). The process of conceptual change would take an individual from the incorrect transformational conception to the correct variational one.

The variational view is the accepted Darwinian theory that variation exists randomly within a species and is not determined by purpose or intention. This variation is essential for the process of natural selection, as some individuals will have traits that make them better or worse suited to their environment, and the population will experience differential survival, which in turn leads to differential reproduction. The subsequent generation will show a greater frequency of any beneficial trait and a reduction in any trait that has a detrimental effect on survival. This continues as long as the environment is stable. To use giraffes as an example – in a giraffe population the genetic variation (gene pool) will cause a variety of neck lengths. Having a longer neck is a beneficial trait as a greater volume of food can be consumed, so these individuals are more likely to survive until reproductive maturity and

produce offspring which will inherit the long neck. Correspondingly, individuals with shorter necks are likely to produce fewer offspring, so the subsequent generation will have a greater frequency of longer necks.

The transformational view is the rejected Lamarckian approach which focuses on the inheritance of acquired characteristics that an individual has obtained due to the benefit that characteristic provides during its lifetime. The offspring then inherit the beneficial developed trait; for the giraffes a longer neck is achieved by repeatedly using the neck to reach higher leaves. When those individuals reproduce the offspring will inherit the longer neck and the subsequent generation will have longer necks.

These two conceptions exist along with a transitional phase during which individual's explanations may exhibit characteristics of both a variational and transformational understanding (Shtulman and Calabi, 2013). For example, an explanation could show a good understanding of variation and its relevance but then misunderstand that only the beneficial traits are inherited by the offspring.

1.5. Curriculum changes

The National Curriculum for England was first introduced in 1989 (National Curriculum, 1989) and has been reformed several times since, most recently in 2014 (National Curriculum in England, 2013). Each version of the curriculum sets out what should be taught in each of the four Key Stages (KS) where science is a statutory requirement. Key Stage 1: ages 5-7, Key Stage 2: ages 7-11, Key Stage 3: ages 11-14 and Key Stage 4: ages 14-16.

The original 1989 curriculum was set out as 17 Attainment Targets; each containing content statements which increased with difficulty over 10 levels (levels 1-3 during KS1, 2-5 during KS2, 3-7 during KS3 and 4-10 during KS4). One of the Attainment Targets was called *Genetics and Evolution*, even though evolution is not actually mentioned in any of the curriculum statements until KS4, with only variation, extinction and inheritance included at KS2.

Due to the large number of attainment targets and content statements, the science curriculum was urgently reviewed in 1991 as effective assessment was proving unmanageable for teachers. The content was reorganised into five Attainment Targets and the number of content statements was reduced from 409 to 178. The newly created *Life and Living Processes* encompassed *Genetics and Evolution* and three other original attainment targets which removed any mention of evolution from the entire curriculum. Variation, adaptation and inheritance remained at KS3 but were no longer included at KS2.

During the next two reforms the levels were removed and instead the curriculum was organised into the distinct Key Stages for the first time (National Curriculum, 1995 and National Curriculum for England, 1999). Both included evolution at KS4 for both single and double science GCSEs, domestication and inheritance at KS3 and variation and adaptation at KS2. Changes were only made to the KS3 and KS4 curriculum in 2007, as the planned primary reforms were discarded when the government changed in 2010 which meant the major overhaul of the curriculum in 2014 saw the first changes to science at primary school since 1999.

Evolution was included for the first time in the Primary National Curriculum to be taught from September 2014. The National Curriculum in England (2013) suggests teaching evolution and inheritance in Year 6, the final year of primary school, and the ideas to be taught are written below, taken from the National Curriculum in England (2013 p32).

Pupils should be taught to:

- Recognise that living things have changed over time and that fossils provide information about living things that inhabited the Earth millions of years ago
- Recognise that living things produce offspring of the same kind, but normally offspring vary and are not identical to their parents
- Identify how animals and plants are adapted to suit their environment in different ways and that adaptation may lead to evolution

Justification for curriculum changes are not provided by the government and it is unclear why evolution was included specifically for this age group. In the United States biological evolution appears in the 'Before Grade 8' (UK Year 9, aged 13-14) standards (National Research Council, 2012) but components such as adaptation and inheritance are taught much earlier in Grade 3. The Next Generation Science Standards (National Research Council, 2013) are set out clearly and there appears to be a progression of the key science concepts throughout the grades.

The National Curriculum statements that were shown above are introduced after six years of formal science teaching without any prior preparation, unlike the US guidelines which are much more detailed and reviewed by Wagler (2012). The lack of research with primary-aged children also means that it is unclear whether the children can cognitively process the topic of evolution at the ages suggested in the National Curriculum. A comparison of what

is expected in science learning, deemed relevant for evolution, in each year can be seen in Table 1.1. The statements in the table are taken from The Next Generation Science Standards (National Research Council, 2013) and National Curriculum in England (2013). It is worth noting that the US does not have a National Curriculum, only guidelines and US States are not required to adopt The Next Generation Science Standards. According to the National Science Teaching Association (NSTA, 2014) 20 out of 50 states (accounting for 36% of US students) have fully adopted the standards and 24 have developed their own framework using the guidelines. As such, it is unclear how many students in the US actually learn about evolution at school.

Table 1.1. A comparison of the England and US curriculum

	US	England
Grade 1/Year 2	<p>Adult plants and animals can have young. In many kinds of animals, parents and the offspring themselves engage in behaviours that help offspring to survive.</p> <p>Young animals and plants are very much, but not exactly like, their parents.</p> <p>Individuals of the same kind of plant or animal are recognisable as similar but can also vary in many ways.</p>	<p>Identify that most living things live in habitats to which they are suited and describe how different habitats provide for the basic needs of different kinds of animals and plants.</p> <p>Notice that animals, including humans, have offspring which grow into adults.</p>
Grade 2/Year 3	<p>There are many different kinds of living things and they exist in different places on land and in water.</p>	
Grade 3/Year 4	<p>Reproduction is essential to the continued existence of every kind of organism. Plants and animals have unique and diverse life cycles.</p> <p>Many characteristics of organisms are inherited from their parents.</p> <p>Different organisms vary in how they look and function because they have different inherited information.</p> <p>Other characteristics result from individuals' interactions with the</p>	<p>Recognise that environments can change and that this can sometimes pose dangers to living things.</p>

	<p>environment, which can range from diet to learning. Many characteristics involve both inheritance and the environment.</p> <p>The environment also affects the traits that an organism develops.</p> <p>Some kinds of plants and animals that once lived on Earth are no longer found anywhere.</p> <p>Fossils provide evidence about the types of organisms that lived long ago and also about the nature of their environments.</p> <p>Sometimes the differences in characteristics between individuals of the same species provide advantages in surviving, finding mates and reproducing.</p> <p>For any particular environment some kinds of organisms survive well, some survive less well and some cannot survive at all.</p> <p>When the environment changes in ways that affect a place's physical characteristics, temperature or availability of resources, some organisms survive and reproduce, others move to new locations, others move into the changed environment and some die.</p> <p>Populations live in a variety of habitats and change in those habitats affects the organisms living there.</p>	
Grade 4/Year 5		Describe the life process of reproduction in some plants and animals.
Grade 5/Year 6		<p>Recognise that living things have changed over time and that fossils provide information about living things that inhabited the earth millions of years ago.</p> <p>Recognise that living things produce offspring of the same kind, but normally offspring vary and are not identical to their parents.</p>

		Identify how animals and plants are adapted to suit their environment in different ways and that adaptation may lead to evolution.
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In Year 7 most children in England move to a secondary school and the curriculum statements then become more aligned with the US curriculum as seen below.

Grade 6/Year 7	<p>Genes, chromosomes and alleles affect the traits of an individual by controlling protein production.</p> <p>Mutations can arise that alter the structure and function of proteins.</p> <p>Organisms can reproduce sexually or asexually and this determines what is inherited.</p> <p>The fossil record documents the change in life forms throughout the Earth's history. Anatomical and embryo similarities and differences allow the reconstruction of evolutionary history.</p> <p>Natural selection leads to the dominance of certain traits and the suppression of others. Traits that support successful survival and reproduction become more common.</p> <p>Artificial selection is when humans influence certain characteristics by selective breeding.</p>	<p>Genetic information is transmitted from one generation to the next.</p> <p>A simple model to show chromosomes, genes and DNA.</p> <p>That variation between individuals can be continuous or discontinuous.</p> <p>That variation between individuals means some organisms compete more successfully which drives natural selection.</p> <p>Changes in the environment may leave individuals less well adapted which may lead to extinction.</p>
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1.5.1. Challenges for primary school teachers

The proportion of science specialists within primary school has been estimated to be as low as 3% by The Royal Society (2010) when they analysed data provided by the General Teaching Council about the 199,207 registered primary school teachers in England. Science specialists are teachers who have science qualifications above the compulsory GCSE

(General Certificate of Secondary Education – external examinations taken by nearly all students in England at the age of 16) level. Thus most children at primary school are being taught by a teacher who has not studied science past the age of 16. This raises particular concerns about concepts, such as evolution, which are widely misunderstood in the general population (Evans, Speigel, Gram, Frazier, Tare, Thompson and Diamond, 2010); misconceptions could be unintentionally transferred from teacher to child.

Lack of confidence in their own teaching ability was identified as the major concern facing science at primary school when 300 teachers were surveyed (Murphy, Neil and Beggs, 2007). Confidence levels were lower with more abstract topics such as light and friction (66%) compared with the more concrete topics such as labelling plants and the water cycle (85%).

There is no doubt that evolution is conceptually challenging and, as a recent addition to the curriculum it is possible that this will pose a great challenge to primary school teachers.

1.6. Acceptance of evolution

Evolution is a topic that often provokes comments concerning acceptance in view of diverging religious beliefs. Accepted scientific wisdom about evolution is rather different from a number of religious beliefs and the two viewpoints co-exist in the population. Controversy often arises when evolution is taught as evidence-based fact in science education in schools (Rosengren, Brem, Evans and Sinatra, 2012).

Despite evolution being accepted by the scientific community as fact, this is not the case for the general public. Miller, Scott and Okamoto (2006) compiled the results from surveys in 34 countries to produce the graph in Figure 1.1 illustrating the responses as to whether the participants accept evolution as true, false or if they are unsure.

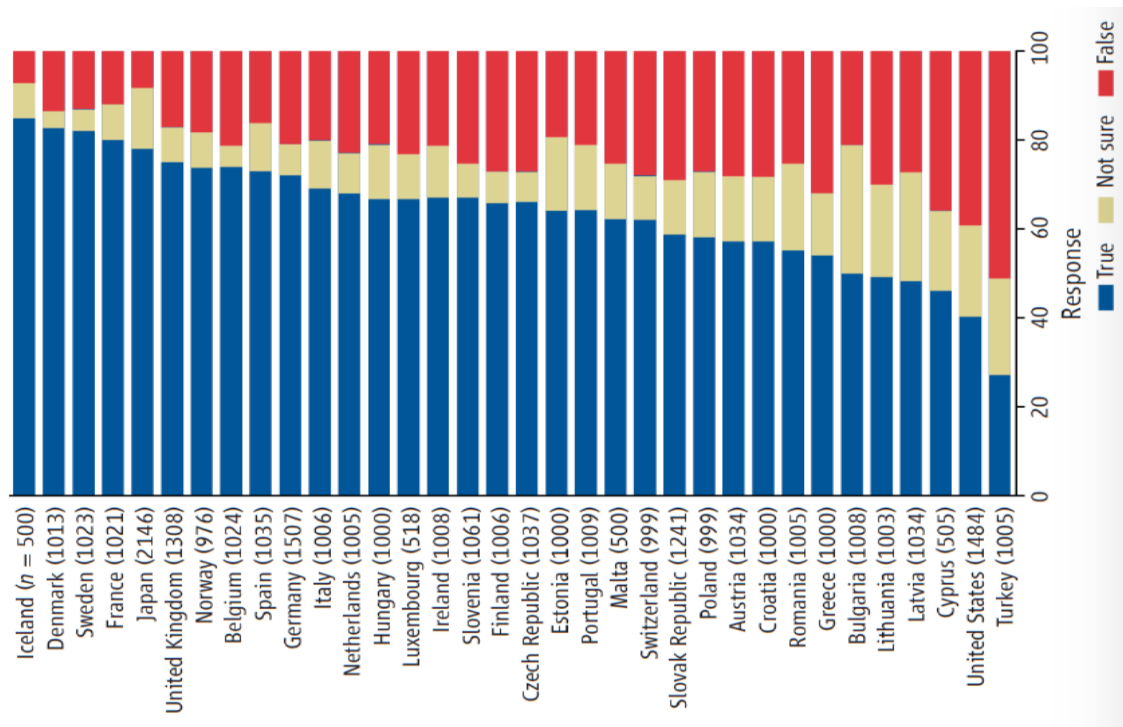


Figure 1.1: Taken from Miller, Scott and Okamoto (2006 p765)

Figure 1.1 quantifies the level of acceptance but participants were asked the question without justification and the reasons for non-acceptance may not be of a religious nature. Allmon (2011) categorises the reasons for non-acceptance into five groups; inadequate understanding of empirical evidence supporting evolution, inadequate understanding of the nature of science, religion, psychological factors (essentialism as discussed in section 2.2.1 of the literature review), and political and social factors.

Inadequate understanding could be improved by effective instruction but the religious, political and social factors pose a greater challenge to understanding of evolution as beliefs have personal value and can often outweigh educational instruction acting as a barrier to learning (Evans, 2008). Justifications for change to these beliefs need to be very convincing as great significance can be placed on an individual's belief and changes can have emotional consequences (Smith, 2010). Weisberg, Landrum, Metz, and Weisberg (2018) suggest that Americans' acceptance of evolution is highly influenced by their scientific understanding and as such, it might be amenable to change with clear instruction.

The study is concerned with the scientific understanding of evolution, not the acceptance or belief of the theory but discussions of a religious nature may have arisen and this would have been dealt with sensitively and appropriately. Throughout the study religion was not mentioned by any of the participants or parents.

1.7. Rationale for the proposed study

The UK government has acknowledged the importance of evolution by adding it to the primary National Curriculum. There are two reasons why teaching evolution is important. Firstly, it is a fundamental concept that underpins what we know about the natural world and ultimately allows us to understand the diversity of life, which has an impact on STEM career choices as well as wider global issues such as climate change. Secondly, the evaluation of existing evidence when working towards an understanding of evolution is critical if students are to make informed decisions and develop reflective thinking, which is an essential life skill. The style of intervention used in this study was selected to promote thinking skills and is discussed further in section 2.9 of the literature review.

The widespread misunderstanding of evolution (summarised by Gregory, 2009) by adults and secondary school students internationally is apparent, but there is very limited research with primary-aged children and a complete absence of studies in the UK. Although UK has high levels of acceptance (Miller, Scott and Okamoto 2006), little is known about the level of understanding due to a significant lack of research.

Survey data (The Royal Society, 2010) has shown there are a very limited number of specialised science teachers in primary schools which has two potential consequences. Firstly, incorrect evolutionary understanding may be prevalent among teachers and therefore among students. Secondly this may impact on teachers' confidence levels for both their subject knowledge and pedagogical content knowledge.

The current research has made several important contributions to knowledge. Firstly, the development and thorough piloting of an assessment tool that can be used to describe the understanding of six evolutionary concepts will fill a gap as currently no existing assessment tools exist. The second contribution will be the detailed description of conceptual understanding that the assessment tool provides for this particular group of participants. Thirdly an evolution intervention has been developed and rigorously evaluated to promote the understanding of the six concepts taught which could have practical implications for teaching evolution in the classroom.

Evolution is a complex theory and is difficult to measure its understanding as it involves several concepts, so the study measured six implicit concepts as identified by Shtulman (2006). Existing interventions have not addressed all six concepts so the study aimed to

investigate whether explicitly teaching the six concepts would facilitate an improved understanding.

1.8. Structure of thesis

The structure of the thesis is presented below, and includes six chapters: 1) introduction, 2) literature review, 3) methodology, 4) quantitative findings – evolution assessment, 5) quantitative findings – cognitive development and 6) discussion.

1. Introduction: The chapter introduced the aims and background information relevant to the study including the importance of understanding evolution as both a concept itself and its contribution to scientific literacy. An overview of evolution in the primary national curriculum is given to present the context in which the study is situated. An overview of the rationale and contribution to knowledge is presented.

2. Literature Review: The chapter presents the literature review pertaining to the following topics:

- a) *Misconceptions about evolution:* This section introduces the literature describing the challenges encountered when trying to understand evolution and what the common misconceptions are.
- b) *What makes evolution difficult to understand:* Intuitive theories and essentialist bias are described as possible reasons for the existence of misconceptions about evolution.

c) Conceptual change: This section introduces the process of conceptual change when learning different concepts. The Piagetian background is described and the alternative knowledge-as-theory and knowledge-as-elements perspectives are given as well as the educational implications of each.

d) Measuring the understanding of evolution: The six concepts (variation, inheritance, adaptation, speciation, extinction and domestication) that provide the theoretical framework for the study are described using the giraffe as an example. The two opposing conceptions (variational and transformational) are discussed and defined for each of the six concepts.

e) Teachers' understanding of evolution: This section will describe the existing literature about how teachers understand. The limited studies with primary school teachers are discussed as well as high school biology teachers.

f) Primary school children's understanding of evolution: This section describes the research that has been conducted with younger children to investigate their understanding of evolution and the constituent concepts before they have had any formal instruction at school.

g) Interventions for primary aged and older children: There is limited existing research with younger children but the intervention studies that do exist are considered in this section.

h) Cognitive Acceleration through Science Acceleration: This section provides the background to the CASE research and why it was originally developed. The theoretical background and the principles of each lesson are described. Existing

interventions are detailed along with a discussion of commercially available programmes.

3. Methodology: This chapter describes the methodology employed in the study and begins by presenting the two hypotheses and detailing the research design. The participants, their recruitment the schools and schedule are described. The assessment measures are then detailed including a full description of how the evolution assessment was designed and piloted before being used in the study. The development of the evolution intervention sessions is described and the plan for each session is provided, set out using the CASE principles. Finally the ethical considerations and the analyses are set out.

4. Findings from evolution assessment: This chapter addresses the first hypothesis by analysing the evolution intervention and the assessment results. The intervention sessions are evaluated by giving the aim, the technical vocabulary introduced, describing the activities and information is given about the school context and the types of questions asked by the participants. The quantitative results from multiple-choice part of the assessment are analysed before the written justifications are analysed using a scoring system. Finally the use of technical vocabulary is analysed.

5. Findings from cognitive development: This chapter addresses the second hypothesis by discussing the CASE principles within the intervention and then a quantitative analysis of the results from the measure of cognitive development.

6. Discussion: This chapter discusses the key findings from the two results chapters and provides possible explanations for the results. The contributions to knowledge, strengths,

weaknesses and educational implications are discussed and potential future directions suggested. The thesis closes with a conclusion.

Chapter 2: Literature Review

This chapter describes the existing literature and identifies the gap filled by the study. First, the misconceptions about evolution will be discussed and suggested reasons are given for the prevalence of misconceptions. Secondly the mechanism of conceptual change will be discussed along with a description of the two opposing conceptions about evolution and the theoretical framework used in the study. The existing literature about teachers' and childrens' understanding of evolution will be presented before Cognitive Acceleration through Science Education (CASE) is discussed in detail. This includes its development and the implementation of the various CASE-based interventions to date.

2.1. Misconceptions about evolution

There is a body of research which confirms that evolution is difficult to understand and that widespread misconceptions exist in the population. These misconceptions have been found in primary school children (Berti, Toneatti and Rosati, 2010; Samarapungavan and Wiers, 1997; Solomon, 2002), middle and secondary school children (Beardsley, 2004; Settlage, 1994; Spindler and Doherty, 2009; Yates and Marek, 2015), biology undergraduates (Shtulman, 2006), teachers (Deniz, Donnelly and Yilmaz, 2008; Yates and Marek, 2013) and other adult populations including museum visitors (Evans, Speigel, Gram, Frazier, Tare, Thompson and Diamond, 2010).

2.1.1. Terminology

The term misconception is disputed by some as the viewpoint expressed by the participant

is logical '[m]any researchers object to the term 'misconception' because, from the student's viewpoint, the ideas expressed are logical' (Sneider and Ohadi, 1998 p66).

Misconception will be used in the current study as it emphasises the aim of the research which is to aid students in their correct understanding to be in line with the accepted scientific understanding. When authors have used a synonym such as misunderstanding or alternative conception these will be used to describe their findings.

The two alternative conceptions of evolution, variational and transformational, were described in the introduction. There are many misconceptions described in the literature but the four listed below are the most commonly reported (Gregory, 2009) and reflect a transformational understanding.

- That the use of a trait is the cause of its growth in an individual which is then inherited by offspring.
- That new traits appear because they are necessary for survival rather than by random mutation.
- That all members of a population change to suit the environment rather than differential survival and differential reproduction.
- That individuals deliberately change to suit their environment and these intentional changes are inherited by offspring.

The prevalence of misconceptions in the evolution literature indicate that it is a difficult concept to understand; it might be very difficult for children and their previous ideas might be resistant to educational instruction, as the misconceptions persist in adulthood.

2.2. What makes evolution so difficult to understand?

In the absence of instruction individuals develop intuitive ideas about scientific concepts. Naïve theories, as they are often called, are created in response to an individual's experience. Naïve theories often resemble the historically early understanding of a topic until refuted by empirical evidence. This has been illustrated in various scientific domains such as thermodynamics (Wiser, 1988) physical chemistry (Smith, Carey and Wiser, 1985) amongst others (Driver, 1994). Shtulman (2006) argues that much of the research preceding his own about the understanding of evolution failed to demonstrate whether naïve theories exist for evolution as the analyses were too broad to make meaningful conclusions at a theoretical level.

Early evolutionary theorists such as Lamarck (1809) exhibited a transformational understanding; the tendency was to focus on each individual and how they transform over time. Psychological research suggests that essentialism, an intuitive theory, may be incompatible with the correct understanding of evolution and elicit transformational explanations.

2.2.1. Essentialism

Essentialist beliefs focus on the everyday world as stable and unchanging where objects and living things possess specific characteristics which give them identity and function. From a biological perspective – living things have an *essence* at their core which has causal power on behaviour and appearance. For example, a leopard is a leopard at birth and its spots are consequences of the fact that is a leopard – it would still be a leopard if it had no

spots.

Essentialist bias allow reliable predictions to be made about the everyday world and how living things may look or act based on previous experience. Being able to generalise about species is commonplace within biology and allows classification and grouping of living things which all aid a better understanding of biodiversity and the living world. Biological sciences often utilise information gathered from a few individuals and generalise this to the entire species (Shtulman and Calabi, 2013) as observing or sampling an entire species is not feasible.

Despite the everyday reasoning essentialism offers and its utility within biological sciences, it acts as a barrier to the understanding concepts fundamental to the understanding of evolution, such as the variation within species. The essentialist focus on the variation between species – e.g. what makes a leopard different from a lion – results in the assumption that all leopards are identical and all lions are identical.

The prevalence of misconceptions across many populations indicates that intuitive theories, such as essentialism, cause a more general cognitive bias, rather than poor teaching or population specific factors. Several studies by Shtulman and his colleagues (Shtulman, 2006; Shtulman and Calabi, 2012; Shtulman and Schulz, 2008) have demonstrated empirically that essentialist misconceptions are inter-correlated with each other: if an individual holds such beliefs for inheritance, they will most likely hold the same beliefs for speciation. Shtulman argues that the correlation of transformational misconceptions represents an integrated alternative theory of evolution as opposed to pieces of incorrect knowledge.

The transition from an intuitive transformational to a variational understanding may require a radical re-structuring of ideas to achieve the correct scientific understanding, a process called conceptual change (Vosniadou, 2013). The assessment used in this study investigated whether the participants exhibit transformational or variational reasoning and whether an intervention can influence their understanding.

2.3. Conceptual change

Conceptual change is a research field that emerged from the convergence of Piagetian developmental research and studies examining conceptual understanding within science education. Conceptual change theories examine the relationship between concepts and how they change over time for an individual. In the context of science learning, conceptions have been defined as:

the learner's internal representations constructed from the external representations of entities constructed by other people such as teachers, textbook authors or software designers (Treagust and Duit, 2008 p298).

The learning process involves children being able to create different representations of entities so they can process difficult and abstract concepts. Science as a subject lends itself to the possibility of multiple conceptions and often children arrive in formal schooling with ideas that are resistant to change despite being incorrect. Vosniadou (2013) includes the theory of evolution in her list of scientific topics that require radical conceptual change as a counterintuitive concept that is greatly misunderstood.

Conceptual change as a research topic was heavily influenced by the developmental psychologist Jean Piaget and the Piagetian model of cognitive development is shown in Figure 2.1. Assimilation is the processing of a new situation using existing knowledge and equilibrium is reached when most new information can be dealt with this way. When a new situation is encountered and it cannot be understood using existing knowledge, the person is in a state of disequilibrium and the new information must be accommodated by adjusting existing knowledge. New information will then be processed by assimilation until further adjustment is necessary if disequilibrium is reached again.

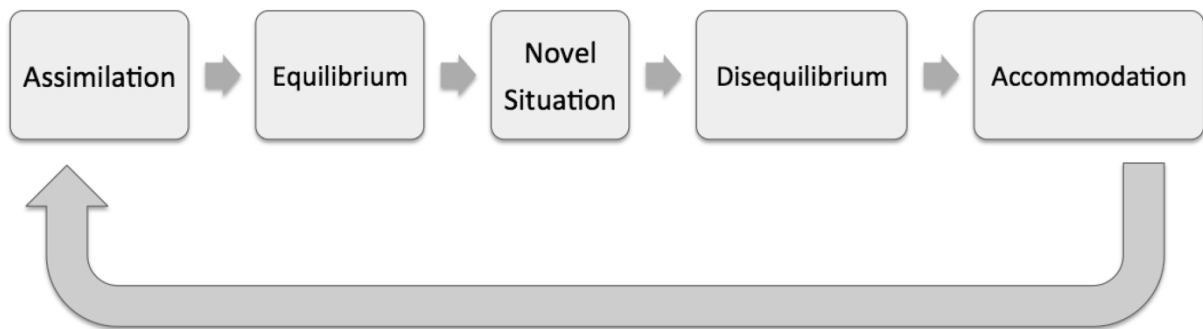


Figure 2.1: Piagetian model of the cognitive development process

Disequilibrium stimulates the thinking process for the child and therefore the role of an educator is to create disequilibrium where it does not exist to induce curiosity and higher level thinking in the child (Wadsworth, 1996) which forms the basis of the conceptual change approach to teaching.

Conceptual learning in science has been an area of interest for many years as science is an area that lends itself to the development of misconceptions. Much work has gone into identifying misconceptions in a variety of populations across many scientific topics and an extensive review was published by Duit (2007), but this is beyond the scope of this chapter.

Gregory (2009) provides a summary of the misconceptions found in the evolution literature. By identifying the areas of misunderstanding the dissatisfaction stage can be induced by the students themselves or facilitated by teachers.

There are two competing theoretical perspectives about conceptual change which have implications for any educational instruction.

2.3.1. Knowledge-as-theory perspective

The knowledge-as-theory perspective is influenced by the Piagetian notion of accommodation; if a learner can solve problems using their existing knowledge they will continue to do so until changes are required. If the learner abandons their existing conceptual understanding to accept a scientific one, conceptual change has occurred.

Posner, Strike, Hewson and Gertzog (1982) proposed criteria for when conceptual change is likely to occur. The new conception must be: intelligible, it should make sense to the learner; plausible, it must be seen as true; fruitful, it must be useful for the learner.

Misconceptions are resistant to change and can restrain learning; there are often multiple misconceptions integrated into one intuitive theory, which all need to be altered for conceptual change to be successful (Posner *et al*, 1982).

Chi (1992) suggests that conceptual change requires an ontological shift between categories, which is considered under the knowledge-as-theory perspective. Ontological categories refer to the kinds of existence in the world such as objects, events, processes and ideas. The different categories have mutually exclusive attributes. When there is a

mismatch between a person's conception and the reality at the ontological level, a robust misconception exists, which is very difficult to resolve.

Misconceptions about evolution are often across ontological categories. The transformational tendency to focus on an individual organism (as an object) and not on the process at the population level requires an ontological shift if conceptual change is to occur. At the process level, there are further misconceptions, evolution is seen as a direct process, where the components are directly causal rather than an emergent one where the collective interaction of all the components leads to an emergent outcome (Smith, 2010). Emergent processes are more difficult and require instruction whereas misconceptions with direct processes can be self-corrected by the learner (Chi, 2005).

2.3.2. Knowledge-as-elements perspective

The knowledge-as-elements perspective states that naïve theories are not really theories, as people hold unstructured collections of many simple elements which have arisen directly from experiences but are not connected to form a theoretical understanding (diSessa, 1993). The learner assumes that 'something happens because that's the way things are' (diSessa, 1993 p112); the ideas are not organised and are used by the learner when necessitated by context.

Empirical evidence exists to support the knowledge-as-elements perspective for certain topics such as thermodynamics (Clark, 2006) but not for evolution which arguably involves more concepts and too many elements for the perspective to be supported.

2.3.3. Implications for educational instruction

Both perspectives hold that knowledge is acquired from daily experience and this knowledge has an impact on formal instruction, usually at school. This knowledge is often resistant to change and conceptual change is a time-consuming process. However, the differences between the perspectives have profound consequences for instructional strategies and curriculum design.

If the knowledge-as-theory perspective is taken, instruction is required to promote dissatisfaction inducing conceptual change by making the correct conception intelligible, plausible and fruitful. The state of dissatisfaction facilitates the discussion of other conceptions, ultimately leading the student to the correct conceptual understanding. If a knowledge-as-elements approach is taken the instruction needs to focus on activating the pieces of knowledge within particular contexts, so a topic such as evolution may straddle many areas of the curriculum. For example extinction may be discussed in a geographical context when links are made to climate change and human impact. However, this approach could reinforce misconceptions, such as humans are the only cause of extinction (Gregory, 2009).

Evolution consists of various concepts and the empirical evidence supports a knowledge-as-theory perspective is taken as misconceptions across concepts are inter-correlated (Shtulman, 2006; Shtulman and Calabi, 2012; Shtulman and Schulz, 2008).

Conceptual change is defined as the process of learning when a substantial revision of existing knowledge is required to acquire new conceptual knowledge (Vosniadou, 2013).

Systematic instruction is usually necessary for conceptual change to occur; this is particularly true for evolution, as it is not a topic experienced in the day to day lives of school children. Conceptual change from a transformational understanding to a variational one is a significant development but it is possible to address constituent concepts that contribute to an overall shift in evolutionary understanding. The evolution intervention designed in the study addressed six constituent concepts and described the level of understanding so different concepts could be identified as stronger or weaker. This study provides evidence about whether 10-11 years olds can learn about the six constituent concepts which are required to have a strong understanding of evolution and whether learning about them can promote conceptual change.

2.4. Measuring the understanding of evolution

Shtulman (2006) identified 6 concepts which coordinate to give an appropriate evolutionary understanding. His aim was to create an instrument that measures the understanding of the integrated concepts that contribute to the current conceived understanding of evolution. The pattern of answers across the concepts is the crucial measure rather than simply the number of errors.

Shtulman piloted various concepts and the six concepts selected will be described below based on the information provided by Shtulman (2006); the giraffe example from the introduction will be continued.

2.4.1. Variation

Many adults will agree that there are differences between individuals of the same species but many do not recognise the importance of this variation with regards to evolution.

Variation between individuals is the factor that allows individuals to be 'selected' for or against depending on environmental pressures. For the giraffes an example of variation would be a range of neck lengths and, assuming a longer neck was advantageous to feeding, the individuals that had longer necks would have the survival advantage. The variation in neck lengths amongst giraffes allows differential survival and therefore differential reproduction.

2.4.2. Inheritance

In many species, offspring resemble their parents but which traits or characteristics are passed on to the next generation is determined by the genetics of the parent regardless of whether that trait is beneficial or not. Any trait acquired during an individual's lifetime will not be inherited by the offspring. In the giraffes, two parent giraffes with short necks that managed to stretch their necks would still have offspring with short necks as their genetic information has not been altered by the environmental change of stretching.

2.4.3. Adaptation

Organisms being adapted to their environment is not too complex an idea but adaptations are often seen as only the outcome of evolution. The ongoing relevance of adaptation as a cause of differential survival which further drives evolutionary changes is often overlooked.

The better adapted giraffes, which have longer necks, are more likely to survive to reproductive maturity than giraffes with short necks. The frequency of long-necked giraffes will increase in subsequent generations as reproductive success will have been in their favour.

2.4.4. Domestication

Humans have interfered with evolution by domesticating many crops and animals used for food. Individuals that exhibit traits or characteristics that are advantageous to humans are selected and allowed to reproduce. The traits being selected are often not beneficial to the survival of the animal and would not have appeared in such high frequencies without domestication, which is also called artificial selection or selective breeding. Giraffes have not been domesticated, but if short giraffes were desirable, only the shortest males and females would be allowed to breed in each generation decreasing the height of the giraffe population with each subsequent generation.

2.4.5. Speciation

Speciation occurs when two groups of organisms are isolated from each other and genetically diverge and can no longer breed together to produce fertile offspring. These two species will always share a common ancestor regardless of any further evolutionary changes and additional occurrences of speciation. If a group of giraffes were separated into two smaller groups by a newly-built fence and food sources were varied on either side of the fence, over many generations the two giraffe populations might have adapted to their environments, diversifying from each other.

2.4.6. Extinction

Extinction is when there are no living individuals of that species left; many are familiar with mass extinctions and human-caused extinction. Extinction is far more common than the well-known examples and is closely linked to the differential survival rates discussed in adaptation. If a greater number of individuals are dying before they reproduce than are being born, over time numbers will decline and eventually the species will become extinct. If the giraffe's food source grew much higher up, only the very tallest giraffes could reach the food, so many would die before reaching reproductive maturity. Far fewer giraffes would reproduce, resulting in a gradual decline in numbers. This on-going type of extinction is far more common than animals being hunted or becoming extinct after an asteroid impact.

2.4.7. Variational or transformational

As described in section 1.4 Mayr categorises the understanding of evolution as variational or transformational and Shtulman (2006) classifies the understanding of these six concepts in the same way. Shtulman hypothesised that they would be consistently classified across examples for the same people. However, he found that this was not always the case; some individuals showed mixed patterns. Shtulman concluded that these mixed patterns were displayed by people who were in transition from a transformational to a variational understanding. Table 2.1 summarises the variational and transformational interpretations of the six concepts as described by Shtulman (2006).

Table 2.1: Summary of variational and transformational interpretations adapted from Shtulman (2006).

	Variational	Transformational
Variation	Individual differences drive selection.	Individual differences are non-adaptive.
Inheritance	The heritability of a characteristic is determined by genetics.	The heritability of a characteristic depends on how beneficial it is.
Adaptation	Adaptation depends on differential survival and reproductive ability.	Adaptation occurs regardless of differential survival.
Speciation	All species share a common ancestor.	Only closely related species share a common ancestor.
Extinction	Extinction is more common than adaptation.	Adaptation is more common than extinction.
Domestication	Species can be domesticated by humans by selective breeding.	Species can be domesticated by humans by changing individuals.

The definitions given by Shtulman (2006) are used in the thesis but it is important to clarify that in the extinction interpretation in Table 2.1. *adaptation* is used to mean the process of adaptation leading to speciation rather than smaller changes that happen more frequently.

The six concepts exhibit a balance between microevolutionary (variation, inheritance and adaptation) and macroevolutionary (domestication, speciation and extinction) ideas. This study employed the six concepts described by Shtulman in the assessment of children and the intervention design as the theoretical framework.

2.5. Teacher's understanding of evolution

Evolution as a theory, is not often encountered in daily life and is normally introduced during formal science education. That said, the constituent concepts are likely to be encountered and misconceptions may arise as individuals try to make sense of the phenomena they are observing. Eberback and Crowley (2009) highlight the difference

between simply observing and observing scientifically, and how without context or support for the latter children can fail to gain a deeper understanding. Instead they might develop naïve theories and misconceptions which are resistant to change as they have helped the individual make sense of the world around them, even if they are scientifically incorrect. As a result effective instruction by teachers is essential for future understanding.

Primary school teachers in the UK are predominantly non-science specialists (The Royal Society, 2010) and it is documented that they lack confidence when approaching science and tend to avoid it as a result (Harlen, Holroyd and Byrne 1995; Murphy, Neil and Beggs, 2007). As the understanding of evolution seems to cause misunderstandings for many it can be safely assumed that primary school teachers also have the same misconceptions.

The following section presents the existing research with primary school and high school teachers from various countries. If misconceptions are prevalent across a range of cultures and school systems it could suggest that they are a result of individuals trying to make sense of phenomena they have experienced. This is why misconceptions are difficult to change; they work in everyday life for many purposes.

A study in Greece documented that not only are misconceptions not confronted but they are regularly affirmed by primary school teachers (Prinou, Halkia and Skordoulis, 2011). Only 7 out of the 153 (4.3%) participants gave the correct scientific explanation for evolution and 90% felt it was unnecessary for them to understand it to carry out their jobs as a primary school teachers adequately. The majority (87%) of the teachers felt inadequately prepared by their graduate teacher training courses to teach evolution. Ashgar, Wiles and Alters (2007) conducted a questionnaire survey with 138 pre-service teachers training at a

Canadian university which aimed to determine their acceptance of evolution. Eight volunteer participants were then interviewed for 45 minutes to determine their understanding of evolution. The interviews suggested that most of the participants had limited understanding and yet the only concern they raised about teaching evolution was the controversy rather than identifying their own misconceptions. The generalisability of the qualitative findings is limited but again highlights the need for better training regarding evolution during university courses for teachers.

Due to lack of training and specialist subject knowledge the high levels of misconceptions could be expected in primary schools but do they also exist in high school biology teachers? Rutledge and Warden (2000) administered a questionnaire to 552 high school biology teachers in Indiana, US, which had 68 items of which 21 were about understanding. The analysis revealed only a moderate level of understanding as the mean score was 14.89 (SD=4.05) out of 21 and some of the more challenging questions had noticeably lower scores. Researchers concluded that the teachers are ill prepared to deal with the topic of evolution within classrooms, however it is unclear whether these teachers held biology qualifications or whether they had trained specifically to be a biology teacher.

Yates and Marek (2013) surveyed 76 high school teachers that were teaching introductory biology modules and found a 23% misconception rate and suggested the implication would be teachers fuelling misconceptions amongst their pupils. When looking at the students taught by the same teachers the sample of 993 had a misconception rate of 39.1% before they started their biology courses (Yates and Marek, 2015) but exited with a greater number of misconceptions than before (Yates and Marek, 2014) and the authors suggest this is evidence for misconceptions passing from teachers to students.

These findings are concerning as evolution teaching at high school is the last formal learning of the topic that most students will have unless they go on to study it at degree level. So their lasting impression is being formed by teachers who themselves harbour misconceptions.

2.5.1. Pedagogical content knowledge

Whether teachers understand evolution (content knowledge) or not, is further complicated by whether they have the pedagogical knowledge to teach it effectively. The integration of both pedagogical and content knowledge was termed pedagogical content knowledge (PCK) by Shulman (1986) which he describes as ‘the ways of representing and formulating the subject that makes it comprehensible to others’ (p9) or the transformation of subject knowledge into accessible information for students (Shulman, 1987).

Pedagogical content knowledge is what differentiates an evolutionary scientist from a science teacher capable of teaching evolution. An important element of PCK is that teachers have ‘an understanding of what makes the learning of specific concepts easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning’ Shulman (1986 p9), however as previously discussed many teachers bring their own misconceptions when teaching evolution which might make it difficult for them to identify the mistakes their students are making.

Settlage (2013) suggests that the construct of PCK is noticeably absent from education policy documents due to the lack of clarity in the literature and after years of research there is an incoherence about how best to develop PCK in teachers (Berry, Friedrichsen and

Loughran, 2015). This poses a challenge when training teachers who already have good content knowledge, never mind a topic such as evolution where it can be assumed that teachers might not have the adequate subject knowledge. Hashweh (2013) highlights that experienced physics and biology teachers have difficulty teaching out of their subject specialism, even within the wider science domain and their own teaching philosophy has an impact; teachers taking a constructivist approach are more likely to have developed stronger PCK than those with an empiricist view (Hashweh, 1996).

The intervention in the current study was designed and delivered by a qualified biology teacher with several years experience and a constructivist approach was taken. A similar level of PCK cannot be assumed in primary school teachers in the UK, and as such further research is needed in this area to influence training for non-specialist primary school teachers.

2.6. Primary school children's understanding of evolution

There is very little research investigating primary school children's understanding of evolution, but there is research on young children's understanding of simpler biological ideas.

Inagaki and Hatano (2002) describe children's biological understanding before instruction at school as naïve, that is they develop their own knowledge system to make sense of their experiences, which is different from them having pieces of knowledge that are not integrated. Inagaki and Hatano (2002) found that children as young as 5 can distinguish between living and non-living things and show some biological reasoning by using

analogies, often about humans, such as ‘like people do’. The authors suggest that the personification of animals and plants could reflect a child’s active mind. However, this type of reasoning can create problems for more complex topics such as photosynthesis where an analogy to humans could lead children to conclude that plants are eating water as their food. This is relevant to evolution as humans are often seen as goal-orientated which could lead to assumptions that organisms are purposively adapting within their lifetime.

Inheritance is one of Shtulman’s (2006) six previously described concepts and is often paired with genetic technology as an area of rapid development due to technological advances in recent times. Venville, Gribble and Donovan (2005) conducted a cross-sectional study in which 30 children aged 9-11 (from a larger sample of 90) were interviewed and it was found that children of this age can differentiate between genetic variation such as skin colour, and environmental variation such as clothing preferences. The participants also identified that it was genetic variation that is inherited and could describe why they looked like their parents. If technical vocabulary, such as genes or DNA, had been used in the interview they were asked about this in more detail, if not the interview was stopped early. Over three-quarters (76%) of participants mentioned genes or DNA but very few managed to successfully explain the terms.

The findings from the aforementioned studies are interesting, but as evolution requires the integration of multiple concepts it is difficult to conclude whether understanding inheritance, for example, out of an evolutionary context correlates with their understanding in context. The current study assessed the six constituent concepts needed to understand evolution and provides information about how well 10-11 year olds understand the concepts.

2.7. Interventions with Primary aged children

There have been a few attempts to teach evolution to primary school children but the studies are confounded as they lack control groups and causal inferences cannot be made.

Lehrer and Schauble (2004) implemented a long-term intervention focused on the variation component of evolution with 23 fifth-grade students, aged 10-11, in the US. Their existing teacher delivered around 45 hours of teaching centred around the growing plants in the classroom and the variation observed. The lessons used mathematical techniques, such as graph drawing and extrapolating data to make predictions, to demonstrate variation and post-test interviews were carried out by the researcher using tasks from the lessons as stimuli for the children to respond to. The researchers concluded that the children reasoned about variation in their answers, however much of the interview focus was on mathematical skills and the conceptual assessment of variation is limited. This intervention was time intensive as the lessons totalled 45 hours and measurements of the plants were taken every day so may not be ecologically valid.

Nadelson, Culp, Bunn, Burkhart, Shetlar, Nixon and Waldron (2009) delivered a shorter-term intervention with participants receiving 3-4 hours of lessons over 1 day. The participants were 30 Kindergarten and 34 second-graders from 4 classes in 2 different schools in the US. Lessons were developed according to the curriculum learning standards about evolution for each age group. They used existing resources from textbooks and the internet and adapted lessons to reflect their aims better. The analysis involved classroom dialogue and the products created by the children during the lesson. Photographs were taken during the lessons to gather evidence. The qualitative findings indicated that many of

the children engaged with the topics at this age and demonstrated some knowledge of adaptations when asked to create a model of an aquatic bird. The lack of a post-test does not allow conclusions to be made about long-term learning or the transfer of knowledge. Assessment based purely on tasks carried out during instruction makes it unclear as to whether the understanding is there or whether the completed tasks are just in response to the teacher's instructions.

Berti, Toneatti and Rosatti (2010) interviewed 21 second grade students and 18 third grade students before and after evolution instruction at one school in Italy. Italy has a predominantly Catholic population and the religious education syllabus is written by the Catholic Church and it includes the story of Genesis. However, in the third grade students are exposed to the origin of species theory during science and history lessons and students received around 54 hours of teaching on the topic. Semi-structured interviews were conducted using pictures and questions to assess the children's understanding of evolution. Their responses were coded and placed into 4 categories; creationist, naturalist (transformational), evolutionary (variational) or mixed. The second graders expressed predominantly creationist reasoning whereas the third graders showed mixed reasoning and had mostly left the creationist view behind. However very few had fully understood the evolutionary concepts they had been taught and still expressed transformational ideas.

Campos and Sa-Pinto (2013) trialled a series of five activities in Portuguese elementary schools based on enquiry-based learning and the topics were similar to the current study and included variation, inheritance, adaptation and speciation. The qualitative analyses showed that elementary aged children engaged with the resources, however the age of the participants was not given and the understanding of the participants were not assessed.

A small-scale study with 23 children aged 8-9 in Italy (Berti, Barbetta and Toneatti, 2017) utilised short interviews at pre- and post-test to investigate whether the children are receptive to ideas about Natural Selection given the evidence about cognitive bias (essentialism and intentionality). A constructivist approach was taken, so that the children integrated new and existing information and the lessons were ordered in a similar way to the current study – beginning with variation before moving on to adaptation and speciation, however ten 90 minute lessons were given which is likely to be greater time allowance that would be practical in UK schools. The interviews were coded using four categories, one of which was creationist, and the results showed that the number of evolutionary answers significantly increased at post-test but this was in a fragmentary manner rather than consistently across all the topics which may indicate that children of this age cannot reason about evolution as a whole.

A similar interview style assessment was used by Kelemen, Emmons, Seston Schillaci and Ganea (2014) with 61 younger children aged 5-8 in the US to investigate whether using a picture-storybook about evolution can support children's understanding of Natural Selection. The story was written specifically for use in the research and purposefully avoided any language that would imply essentialism or intentionality. The interview answers were coded as one of four levels, and at pre-test 82% of 5-6 year old participants were assigned level 0 (insufficient knowledge) and this had decreased to 11% at post-test, for the 7-8 year olds there was a decrease from 42% to 6%. The interview questions were about the same organism in the story but results with a novel organism were encouraging and the authors concluded that young children are capable of understanding Natural Selection and using narrative stories is an effective teaching tool.

Care needs to be taken when using stories as there is the potential for misconceptions to be transferred. A narrative story suggested for use in classrooms by Russell and McGuigan (2019) follows a single fish's evolution from water to land focussing on the individual and their beneficial change and is completely void of intra-specific variation and differential survival and reproduction. Whilst Russell and McGuigan (2019) comment that the story offers the opportunity to help children identify fact from fiction, caution must be taken as primary school teachers harbour misconceptions and as such, they might not be well placed to distinguish between fact and fiction when it comes to evolution.

The interventions described have significant limitations, most notably the lack of control groups. The existing research highlights the necessity to conduct an intervention study which employs a control group so that any progress made can be attributed to the intervention. The assessments used in previous studies have been varied and often based on the outcomes of lessons where the children have shown progress on tasks they were directed through during instruction so any transfer of knowledge or longer-term retention is unknown. Some of the intervention lengths are longer than the realistic lesson time that would be dedicated to teaching evolutionary ideas in the UK.

The introduction of evolution in the national curriculum for England in 2014 has unsurprisingly increased the interest in primary school children's understanding of evolution but there is still a significant deficit in the literature to show what actually works (Buchan, Hejmadi and Hurst, 2019). The current study provides a six-session intervention with an assessment that measures the concepts (not activities) being taught so that progress can be ascertained. Additionally the active and unseen control groups strengthen the

confidence of an intervention, if shown to be effective, as the results are less likely to be due to chance.

2.8. Interventions with older children

Natural selection as an evolutionary process is more commonly found in the science curriculum of middle and high school students and as a result there is a greater number of intervention studies with this age group. Beardsley, Bloom and Wise (2012) provide a comprehensive review of intervention studies across all age groups and a study with a pre-test post-test design will be described below.

Beardsley (2004) conducted a teaching intervention over a 2-week period with 86 eighth-grade students in their normal biology lessons in schools in the US. An assessment was constructed using essay and multiple-choice questions adapted from an existing instrument (Bishop and Anderson, 1990). Lessons were based on a historical approach and used enquiry-based teaching to deliver three central concepts; more offspring are born than can survive, heritable variation exists within all populations of organisms and some variations lead to individuals that survive and reproduce better than others which can lead to changes in a population (Beardsley, 2004 p607). The study implemented a pre-test post-test design and the participants were scored to have poor, fair or good understanding; pre-test scores indicated that most (78.7%) students had a poor understanding. Over half the students (52.7%) failed to make progress on the post-test; most of the remainder went from poor to fair and very few participants achieving a good understanding. The author concluded that a greater period of time was needed for significant conceptual change to occur.

Further intervention studies that have employed enquiry-based interventions appear to have the greatest effect on conceptual change (Cavallo and McCall, 2008; Desmastes, Settlage and Good, 1995; Sandoval and Reiser, 2004; Settlage, 1994) compared to reading (Garaedts and Boersma, 2006) or lecture style interventions (Spindler and Doherty, 2009). Enquiry-based learning is characterised by the posing of questions and the creation of an argument which is facilitated by the teacher (Barrows, 1996). This pedagogical approach has its roots in the work of Piaget and Vygotsky and promotes the state of ‘disequilibrium’ necessary for conceptual change. Curriculum programmes have been written with this in mind and the one selected for use in this study is termed Cognitive Acceleration.

2.9. Cognitive acceleration interventions

This section will firstly provide the rationale and background behind the development of cognitive acceleration programmes and their content. It will then review the effectiveness of the existing interventions.

2.9.1. Rationale

Cognitive acceleration programmes began development after the results from the Concepts in Secondary Mathematics and Science (CSMS) were published (Shayer, Kuchemann, and Wylam, 1976). The CSMS was a large scale study carried out in the 1970s involving over 14,000 children and aimed to determine the Piagetian levels of secondary school children in a nationally representative sample. The study was carried out as part of a larger project and instruments were developed to measure the reasoning abilities of children. One of the

measures, the *Volume and Heaviness* science reasoning task, developed was utilised in the current study and will be discussed in the methodology.

The results of the study showed extensive variation between individuals of the same age and Figure 2.2 illustrates the 12-year gap between the least and most able children at each age group. Another concerning finding was that less than 30% of children leave secondary school exhibiting formal operational levels of thinking. Considering these are skills required for higher education courses this can potentially cause problems for both the students and the tutors. The most relevant finding for the current study is that less than 5% of 11 year olds exhibit early formal operational thinking when they start secondary school, even though this is to be expected according to Piagetian theory.

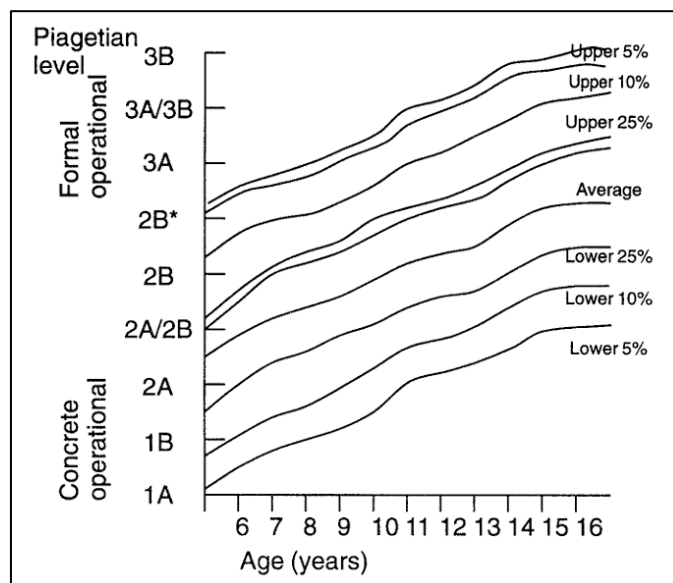


Figure 2.2: Cognitive development by age and ability for boys from CSMS survey taken from Adey and Shayer (1994 p32).

The results from the CSMS survey are disparaging and do not engender confidence in the ability of the British education system to develop children's cognitive ability. The possibility

of improving the situation is appealing and interventions have been developed which aim to accelerate cognitive development and promote higher level thinking skills in the population.

During the 1970s programmes were developed which aimed to train a particular schema. Siegler, Liebert and Leibert (1973) worked with 10 and 11 year olds to determine their Piagetian level of thinking by using the pendulum task, an original task created by Piaget, and training to try and develop their ideas concerning the control of variables. When compared to a control group the intervention group performed better ($p < 0.01$) when re-tested on the pendulum task and exhibited answers demonstrating greater levels of formal thinking. However the generalisability of these findings are limited as the sample size is small, there is no evidence of transfer effects and there may be the implication of practice effects, the participants simply remembered the task and the information provided rather than fully understood it. Another interpretation could be that the study provided evidence for Vygotsky's Zone of Proximal Development (Vygotsky, 1978) as the children's learning potential was being tested. Other studies found similar results (Lawson, Blake and Nordland, 1976; Lawson and Snitgen, 1982; Lawson and Wollman, 1976); thinking can be improved when re-tested using the same schema. All the mentioned studies had small sample sizes, intervention durations of less than two months and no evidence of transfer effects. These attempts to teach thinking at a formal operational level were not successful in that general strategies were not developed and cannot be transferred to a novel situation involving different schema.

2.9.2. Development of CASE

The combination of the poor results from the CSMS survey and acknowledging the limitations of the existing research, a team at King's College London led by Philip Adey and Michael Shayer began to develop the programme known as Cognitive Acceleration through Science Education (CASE).

Cognitive acceleration is defined as accelerating the natural development process towards abstract and multivariate thinking, the *formal operations* as described by Piaget (Adey, 1999). This type of thinking is characterised by being able to manipulate several variables at once, for example being able to consider multiple sides of an argument and see the effects of different variables on the outcome.

Adey and Shayer (1994) reviewed the existing literature and identified the following features that must be present for a successful cognitive acceleration programme; reasonable duration, concrete preparation, cognitive conflict, construction, metacognition and bridging.

The five pillars provide the pedagogical foundation for cognitive acceleration programmes but the content is not specified and as a result the principles have been adapted for many different interventions, including the current study. Science is a subject that lends itself to CA as the Piagetian schemas (Inhelder and Piaget, 1958) are easily identifiable within a science context: relationships between variables, experimental design, observing patterns and analysing evidence. All CASE lessons were designed using the 'five pillars' of cognitive acceleration which are described in Table 2.2.

Table 2.2: The five pillars of cognitive acceleration

Pillar	Description
Concrete preparation	The terms and vocabulary to be used in the lesson must be defined as individuals cannot think abstractly about ideas they have no concrete experience of. For example, if a child has never experienced a hat or a rabbit, it would not be peculiar for a rabbit to be pulled out of a hat because as far as the child knows rabbits may live in hats (Adey and Shayer, 1994).
Cognitive conflict	A discussion is facilitated by the teacher/researcher where the child is questioned about an event or observation they have not experienced before, Piaget's disequilibrium period within the cognitive development process. The child is required to think about what they have seen and accommodate the new information. The teacher questions further to promote higher level thinking skills.
Social construction	The Vygotskian element of the lesson is when children are actively encouraged to discuss the new information they encountered in the earlier cognitive conflict section. They are constructing new ideas and re-establishing their learning equilibrium with the support and challenge of their peers and adults.
Metacognition	The process of thinking about your own thinking is a concept indirectly rooted in both Vygotskian and Piagetian theory and

is an essential element of any programme designed to improve thinking skills (Perkins and Salomon, 1989). The children reflect on their thinking processes so far and are encouraged to discuss any difficulties encountered and how they were solved.

Bridging

The final phase of the process is to assist the children in being able to relate their learning experiences to other contexts so that the schema may be used elsewhere. This promotes the transfer of the thinking process into other areas of life as well as potentially strengthening the understanding of the activities covered in the lesson (Adey and Shayer, 1994).

The pillars are discrete but are often highly integrated within lessons, for example cognitive conflict and social construction are hard to separate when groups discussions are taking place and being facilitated by an adult. Figure 2.3 shows how the pillars are closely linked.

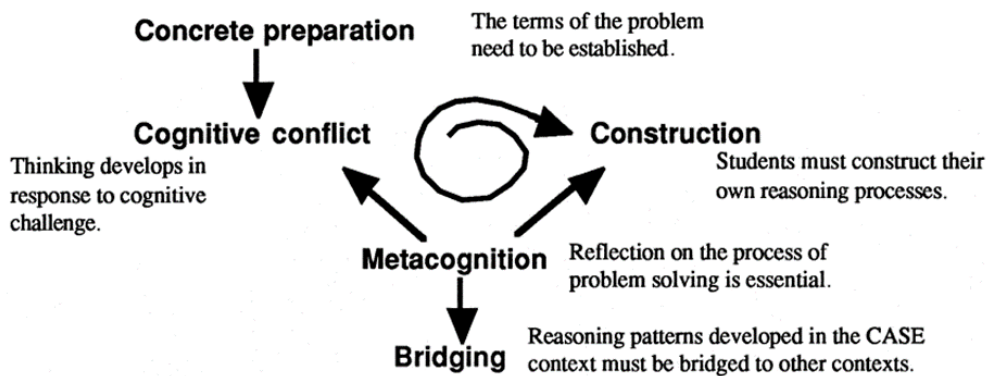


Figure 2.3: Pillars of CASE taken from Adey (1999 p6)

The original CASE programme was designed as an intervention to raise the cognitive abilities of the population who were struggling to access the curriculum. Shayer (2003) says

that ‘the Western environment has produced a cultural deprivation’ (p480) and an intervention is a necessary tactic to increase the proportion of children that can process ordinary instructional teaching at school. Shayer suggests that when the intervention has been practised with all age groups there will be a ‘seamless integration of instruction and intervention (p480)’.

The original project (Adey and Shayer, 1990) began in 1984 and the intervention was designed to last two years which was deemed an appropriate duration to develop higher levels of thinking. Science was chosen as the subject to facilitate the intervention as it lends itself to constructing abstract ideas and the manipulation of variables which are core features of cognitive acceleration interventions. It was decided that the targeted age group would be 11 years old when the participants begin secondary school, as a two-year intervention spread across primary and secondary school would be logistically very difficult. Thirty lessons were drafted which addressed the formal reasoning patterns suggested by Piaget facilitated through a range of science topics that were appropriate for the age group. Each lesson was piloted with at least 2 classes and any necessary amendments to timing and content were made. The main sample consisted of 12 classes from 9 schools that were selected to best represent England and middle-ability students. Control classes were then selected from the same schools to best match the experimental classes producing a study that was quasi-experimental in design. The programme was delivered by the usual science teachers who were given regular training to prepare them for the type of teaching required. The lessons occurred once a fortnight replacing about 25% of normal science lessons.

Two science reasoning tasks were employed at pre-test, including the volume and heaviness science reasoning task which is used in the current study. Different reasoning tests were used

at post-test as well as administering a science achievement test designed to represent the science curriculum. The delayed post-test results were bimodal in that some groups (11 year old girls and 12 year old boys) within the experimental group made significant gains over the control groups whereas others made little or no gains. These results cannot be explained by specific teachers or starting ability as these individuals represented the full spectrum of participants. Adey and Shayer (1994) suggest that some individuals may have been more suited to the intervention style or more 'ready' to develop formal operations. The lack of data from classroom observations or interviews with the participants does not allow conclusions or rigour to be applied to any justification.

The CASE results are more impressive when the externally marked GCSE results are considered. The gains made by the girls in the intervention group were significantly above those in the control groups for their science ($p < 0.01$, $d = .67$), maths ($p < 0.05$, $d = .90$) and English ($p < 0.02$, $d = .75$) GCSE results. The differences for the boys was not significant. The sample size had dropped from the initially recruited due natural attrition and difficulty in maintaining contact with the participants.

2.9.3. Criticism of CASE

The reported benefits of CASE should excite educators and policy-holders due to the observed improvement on the attainment at a national exam level. However there are limitations to the project which may explain some of the discrepancies between individuals. The fidelity of the programme can be challenged as despite the training received, teachers may not have fully embraced the approach and teaching style required for the effective delivery of the lessons. In an attempt to ensure fidelity the project team observed the

cognitive acceleration lessons once a term in each school but this equates to only around a quarter of the lessons delivered. During the remaining lessons the quality of the delivery was unknown and the teachers were not asked for any feedback or questioned about any deviations from the sessions plans. The concerns regarding fidelity are confirmed when the main results are compared to the '*laboratory*' school which was used by the researchers to pilot the material by members of the project team. The gains made by the intervention group were significantly greater than the control group and they were maintained to a greater extent than for the main schools where the programme was delivered by existing teachers. This indicates the fidelity of the programme delivered in the main schools may have been compromised. Nevertheless the main school implementation is more realistic as any application into policy or practice would require existing teachers to implement the programme.

Another limitation of the project is that some of the teachers taught both experimental and control classes and the distinction may have been blurred as they received the training but were only to use the approach with the experimental classes. The control groups, taught by untrained or some taught by trained, were analysed separately but movement of children and teachers between classes during the second year made the distinguished analysis difficult and ultimately diluted any effects of the intervention.

The apparent success of the CASE project has incited other researchers to further analyse the results and publish a critique the original findings. Leo and Galloway (1996) determined that the programme was only beneficial for between 25-50% of the intervention participants and that consideration needs to be given to the motivational and learning styles of children for teachers to tailor the sessions accordingly. They query the lack of theoretical explanation

given by the CASE team as to why not all the participants made progress. The assessment measures have also been criticised by Jones and Gott (1998) who argued for the ‘conceptual dismembering’ of the project to determine the specific aspects which were both significant and realistic for future educational practice. Jones and Gott disputed the use of the science reasoning tasks as a measure of the effectiveness of the programme as ‘such tests are bound to show improvement for a class taught such ideas’ (p 757). Shayer (1999) responded stating that a researcher’s first choice would always be a measure that was grounded in the theory of the intervention and that the long-term effects on the national GCSE exams allay these concerns.

The original CASE programme has been implemented and evaluated internationally with success similar to the UK project. Oliver, Venville and Adey (2012) implemented the CASE lessons in a deprived school in Western Australia. The same measures and teacher training programme was used and a qualitative aspect was added to collect the views of both the participating teachers and students. Endler and Bond (2008) conducted a similar study in the US where they used the CASE materials but utilised different assessment measures and limited teacher training programmes. The results still demonstrated some success indicating gains can be made in sub-optimal conditions. The project has also been conducted in developing countries where the general quality of teaching and training provision is often considerably lower. Mbanjo (2003) followed the same procedure used in the original CASE project in Malawi with older children. The positive results suggest that there may not necessarily be a critical age to implement a cognitive acceleration programme as suggested by Adey and Shayer (1994). Iqbal and Shayer (2000) conducted a study across three schools in Pakistan and used an intensive training programme to educate the teachers in the CASE principles. They identified cultural concerns as some of the teachers did not hold professional

qualifications or were very resistant to the programme and the researcher had to take over the lessons. Significant gains were seen in the schools that were considered to have embraced the CASE teaching style.

The international effects of CASE are promising and with the necessary cultural adaptations gains could be made in developing countries where the level of cognitive ability is often much lower than the high demands of the curriculum (Iqbal and Shayer, 1995).

2.9.4. Further interventions

After the apparent success reported for CASE the same research team developed a programme for 5-6 year old children called CASE@KS1 (Adey, Robertson and Venville, 2002) which began after a request from a local education authority in London who wanted to explore the opportunity to improve the life chances of their most disadvantaged children. During the development of the programme it was decided that the intervention would last for 1 year rather than 2 as the children are much younger, therefore more susceptible, and the content would be generic rather than science-specific which is more appropriate for 5-6 year old children and the teaching style at Key Stage 1 (KS1). The quasi-experimental design involved 5 experimental schools and 5 control schools, totalling an initial sample size of approximately 640 children. The same two Piagetian reasoning tasks were used as pre-test and post-test measures and the intervention consisted of 29 activities which were delivered weekly by the class teachers lasting around 30 minutes each. The activities were given to groups of 6 rather than whole classes to maximise the social construction opportunities for such young children. The results showed significant differences ($p < 0.001$) in the gains made by the experimental group compared to the control group for both the reasoning tasks. When

analysed by gender the boys do not make significant gains on one of the tests. The generalisability was also limited as the schools were all in areas of high deprivation and the longevity is questionable as follow-up tests were not conducted. Transfer effects were also not measured as the pre and post-test measures were the same and so the newly learned skills were not applied into a novel situation. Unlike the original CASE project there was no academic measure at pre- or post-test nor was intelligence controlled for in the analysis.

The described studies involved participants aged either 11-12 or 5-6 and there is little evidence of cognitive acceleration interventions for children in-between. There was one study (Adey and Shayer, 1994) conducted by a teaching university in South Korea where the original CASE study was replicated using participants in the last two years of primary school. The pre- and post-test measures were the Volume and Heaviness Piagetian task, the Ravens SPM, a science achievement test and a science processing skills test which are similar to the measures utilised in the current study. Some statistical differences were found for cognitive ability, primarily for girls, but as the intervention materials had not been adapted for age or cultural considerations this may explain the limited effects. There were no immediate effects on the science achievement measure but there were significant gains made on the science processing skills test which arguably is a better measure of what the intervention was aiming to improve.

All the studies that have implemented CASE have similar designs and measures. The results also illustrate a trend, younger girls appear to be more susceptible to the intervention which may indicate a time-frame where the intervention is most effective. However further studies with different age groups are required to determine whether this is a valid conclusion.

In summary, the results from the collection of cognitive acceleration programmes are promising; cognitive development has been significantly improved when compared to control groups. However all the research has been initiated by the same research team and there is little evidence of a progressive approach when designing the evaluations. The existing studies have implemented similar designs and many published articles have originated from the same study but been presented as a follow up or from a different angle.

Cognitive acceleration programmes have proven successful at improving both academic and cognitive outcomes with both primary and secondary school children (Adey and Shayer, 1990; Adey, Robertson and Venville, 2002) in various countries (Gallagher, Hipkins and Zohar, 2012). Cognitive acceleration shares its theoretical framework with the knowledge-as-theory perspective on conceptual change and was used in the current study as an instructional approach.

2.9.5. Research in Western Australia

Australia and England have almost identical scores on PISA for reading, mathematics and science (OECD, 2016) and the original CASE researchers based in London have worked with a University in Western Australia to evaluate the implementation of the *Thinking Science* programme. In 2012 *critical and creative thinking* was added as a required skill to their National Curriculum and it is suggested that the higher level thinking skills should be taught explicitly (ACARA, 2012). However many teachers were unsure of how to best achieve this (Oliver, Venville and Adey, 2012) and there is sustained interest in *Thinking Science* where it has been adopted as a national initiative with regional hubs providing professional development for teachers (Smith, 2016).

Endler and Bond (2000) conducted a small-scale study in a private secondary school where students regularly changed schools which resulted in a high rate of attrition (45%) and only 29 participants took both the pre- and post-test. The comparison group was formed from students that joined the school later, who had not sat the pre-test, and the post-test data were compared against estimations of the expected cohort progress so the gains need to be treated with caution. They found increased cognitive abilities of the intervention group and the gains made by girls continued once the intervention had ended whereas the gains made by the boys during the intervention did not increase afterwards. Despite its limitations the study raised the profile of CASE in Australia and further studies followed.

A larger-scale quasi-experimental study (n=1318) began in 2010 across seven schools to and preliminary results from schools used as case studies have been discussed but due to the small sample sizes they only reported effect sizes and it is unclear whether they gained significant results.

The two-year *Thinking Science* intervention was implemented with 12 year-old participants in a range of school settings. The pre-test measure was the Volume and Heaviness science reasoning task, which is used in the current study however the matched comparison group was much smaller (n=120) which weakens the significant findings from the study.

The results for both deprived students (Oliver, Venville and Adey, 2012) and students in an academically selective school (Oliver and Venville, 2017) have been described as positive but differential progress was made within the sample. Deprived boys made more progress and the gains were greater in an all-male class. As this was a case-study it is hard to make conclusions without a comparison group but the longer-term impact on science results were

above average when compared to national results which may not have been expected for a deprived population. As expected the students in the academically selective school had higher pre-test scores but did make greater gains than the comparison group (Cohen's $d = 0.687$), who also received the intervention, in a non-selective school.

The fidelity to the original CASE intervention was strong as the teachers received the same professional development training and resources and qualitative interview data showed that most teachers engaged with the training and felt they had embedded the pedagogy into their lessons (Dullard and Oliver, 2012).

The varied results across different groups must be taken into consideration and the positive results need to be viewed with caution but the recent move towards embedding thinking skills in the curriculum, the various applications of cognitive acceleration interventions and the published resources all indicate that the CASE principles are being applied in classrooms and the original results are still convincing.

2.9.6. Commercially available programmes

The research conducted in various countries has shown CA programmes are effective in raising students' level of cognition and academic achievement. The effect of CA programmes is relatively greater than most other researched educational interventions (Higgins, Hall, Baumfield & Moseley, 2005) and is an appropriate choice of teaching style as it promotes understanding of hard subjects.

A programme called *Let's Think Secondary Science* was trialled in 53 schools across England (Hanley, Bohnke, Slavin, Elliott, and Croudace, 2016) and had similarities to the original CASE project: the participants were the same age, the aim was to improve reasoning and the lessons were based on the same principles. However *Let's Think Secondary Science* had fewer lessons and the teachers received significantly less training than the original CASE teachers and the researchers deemed the support from the schools was low as many lessons did not take place as planned. The results showed no improvement in English, Science or Maths attainment at post-test and there was no measure of cognitive development. However there were no significant attainment gains at immediate post-test in the original CASE project either, the positive results were seen at GCSE level.

The original CASE findings have led to commercially available programmes called *Let's Think* for primary school children. For 4-6 year olds the programme is not content specific and uses a range of problem solving activities. For 7 year olds and older the programme is subject specific and covers literacy, maths and science.

Let's Think resources are now content specific, which aligns with the intervention designed in the current study, and resources have been published to show teachers how they can use the CASE principles in their other science lessons. (Shayer and Gamble, 2001). In the original study 25% of normal science lessons were replaced with CASE lessons and schools reported that finding the time to embed the CASE lessons in addition to the science curriculum was challenging. The commercially published *Let's Think* programmes are content specific which may overcome the time restrictions as the curriculum is being covered whilst using the CASE principles.

2.10. Summary of the literature

There is little doubt that evolution is difficult to understand and there are widespread misconceptions across age groups and educational settings. The development of intuitive theories, such as essentialism, act as barriers to learning evolution and these theories are resistant to change. Significant re-structuring of knowledge is often required if evolution is to be correctly understood. Interventions promoting conceptual change using Piagetian principles have been proven successful for other scientific concepts but have not been trialled with primary school children. The CASE programme has yielded impressive results and has been adapted into several different subject areas.

The assessment tools and interventions that exist have been used to inform the current study design taking into account the strengths and limitations of the previous studies discussed in this review.

At present there is a dearth of empirical evidence to show what works when trying to teach evolution effectively, which is concerning when you consider that teachers in England have been expected to do so for several years now. There is an increasing interest in the topic and the current study will contribute to the minimal literature about both the understanding and instruction of evolution at primary school.

Chapter 3: Methodology

This chapter includes the aims, the hypotheses, research design, recruitment and participants, assessment measures, intervention design, analyses plan and ethical considerations.

3.1. Aims of the study

The aim of the study was to examine whether a teaching intervention designed to address the six main concepts in evolution theory was effective in improving children's understanding of the theory. The study implemented an experimental design; randomly assigning participants to the groups at the child level. A pre-test and post-test were utilised to investigate whether there is a relationship between the teaching intervention and children's understanding of evolution.

Evolution is a complex theory; its measurement requires the assessment of the understanding of concepts as identified by Shtulman (2006) as different components of the theory of evolution currently accepted. Previous interventions have not addressed all six concepts so the study aimed to investigate whether explicitly teaching the six concepts would facilitate an improved understanding of all concepts or whether some concepts are more amenable to teaching than others.

3.1.1. Research hypotheses

The following hypotheses have been developed based on the existing literature about evolutionary understanding and cognitive development:

The first hypothesis states that explicitly teaching the six evolutionary concepts will result in conceptual change from a transformational to a variational view. This effect is deemed to be specific to the concept taught and not to be apparent in another scientific concept, namely electricity.

The second hypothesis is that, due to the nature of the teaching programme, which is based on the use of cognitive conflict, discussion and reconstruction of the participants' solutions to problems, there will also be a measurable effect on the participants' cognitive development.

An intervention study was conducted to investigate these hypotheses. An evolution assessment tool was designed and was used in the intervention. The pre-test data will be used to describe the participants' level of understanding of evolution and contribute towards the first hypothesis.

3.2. Research design

The study implemented a random assignment experimental design which utilised a pre-test, teaching sessions and then a post-test. Participants were randomly allocated to one of three groups and the random assignment to groups maximised the chance that the groups would not differ in a systematic way (Punch, 2014). Randomisation was at the pupil level and blocked by classroom, so that factors such as teacher and school were maintained constant across groups.

The post-test provided a measure of the dependent variable and the intervention sessions acted as the independent variable. Pre-test scores provided a baseline standard for comparison of both groups at post-test. The manipulation of the independent variable allowed differential exposure to the treatments for all groups, therefore increasing the probability that post-test differences are due to the intervention.

An experimental design, summarised in Table 3.1, engenders confidence in the causal explanations that link the intervention to the children’s performance at post-test. The design also alleviates any concern over internal validity as the random allocation to groups should control for any extraneous variables that may be anticipated to have an effect on the study as well as any unexpected ones. In view of the relatively small number of participants, a pre-test was used in order to assess whether there were group differences in the understanding of evolution prior to the study. The measure will be used as a covariate in the analysis of results in order to maximise the rigour of the comparison between groups.

Table 3.1: Summary of research design

Group	Pre-tests (Oct 2016)	Intervention (Nov 2016-Jan 2017)	Post-tests (Feb 2017)
Evolution group (n=38)	Evolution assessment, Science reasoning task, WISC verbal reasoning.	Teaching of evolution	Evolution assessment, Science reasoning task.
Electricity group (n=35)		Teaching of electricity	
Unseen control group (n=41)		No teaching by researcher	

Group 1 received teaching on evolution; group 2 acted as an active control group and received teaching on electricity; group 3 was an unseen control group and did not receive any instruction from the researcher. The groups were assessed at pre-test and post-test as whole class groups to prevent researcher bias in the administration of the tests. Without an active

control group receiving science teaching from the researcher it would be difficult to conclude that any differences detected in the evolution group were due to the evolution intervention as time spent learning science with the researcher could be a confounding variable. Electricity is taught in Year 6 at primary school and the researcher has delivered an electricity intervention in a previous study, making it a relevant and piloted choice. This study takes the view that the CASE style of intervention promotes general cognitive development but explicit teaching is required to understand specific scientific concepts. The concepts in electricity are distinct when compared to evolution so only the CASE principles will be replicated across both intervention groups.

Although the intervention was delivered by the researcher, the ecological validity was not greatly compromised as the study took place in the participants' usual school settings, with children working in small groups with their normal class peers and covering a topic that they would have normally studied in Year 6.

3.3. Recruitment

Headteachers from 10 primary schools in Oxford and Bristol were contacted but three responded saying due to the national exam pressure placed on Year 6 children they were not able to accommodate a researcher. Five schools did not respond and two schools were recruited and participated in the pilot and main phase of the study.

3.3.1. School description

The two schools were in different cities and their characteristics were varied.

School 1 was a larger than average primary school in Oxford with two Year 6 classes. Over half the pupils are from ethnic minority groups and the proportion of children with SEN and pupil premium eligibility are above average. The achievement of pupils in reading writing and mathematics is below the expected level in national assessments at entry to school and when they leave in Year 6 according to the school's Ofsted report.

School 2 was a larger than average primary school in Bristol with two Year 6 classes. The majority of pupils are of White British heritage and the proportion of children with SEN and pupil premium eligibility are below average. The achievement of pupils is at the expected level at entry and above average in Year 6 according to the school's Ofsted report.

3.4. Participants

The participants in the study were 114 Year 6 (10-11 years old) children recruited from two large primary schools in Oxford and Bristol.

Across the four classrooms there were 118 potential participants who were sent the opt-out consent form. At the start of the study one parent opted out. Two participants were lost due to missing the initial assessments and one participant left the school which resulted in 114 participants and their demographics are shown in Table 3.2.

Table 3.2. Participant demographics

	Treatment group			Total
	Control	Evolution	Electricity	
Number of participants	41	38	35	114
Number of girls	15	19	18	52
Number of boys	26	19	17	62
Mean age (SD)	10.74 (.53)	10.70 (.53)	10.73 (.58)	10.72 (.55)

3.5. Research schedule

The pre-tests were conducted in November 2016 with participants completing all three assessments within a 10-day period. The intervention sessions began in November 2016 and ran until February 2017 with a three-week break over the Christmas holidays. The post-tests were conducted within two weeks of the completion of the intervention, School 1 had the February half-term holiday in-between finishing the intervention and completing the assessments.

The evolution intervention consisted of six sessions and all sessions were given. The electricity intervention was initially designed to also have six sessions but due to some scheduling and logistical issues only four sessions were given to participants in the electricity group.

Registers were taken for each session. Due to absences or other school-based activities such as music lessons 22% of participants missed one session and 5% missed two sessions. No participant missed more than two sessions.

3.6. Measures

Pre-test and post-test measures were selected to assess the children and allowed the hypotheses to be tested. At pre-test and post-test the participants completed an evolution assessment and a Piagetian science reasoning task. Additionally, at pre-test a measure of verbal reasoning was administered to be used as a covariate in the statistical analysis.

3.6.1. Development of the evolution assessment for primary school children

As highlighted in the literature review there was no existing instrument to assess primary school children's understanding of evolution. A significant contribution of the current study was the development of an instrument, which was developed and trialled in a pilot study. The process of development and information on the pilot data are described in this section.

3.6.1.1. *Conceptual analysis*

Existing written instruments designed to assess older children and adults were consulted to define the concepts to be assessed. The Conceptual Inventory of Natural Selection, developed by Anderson, Fisher and Norman (2002) assesses the understanding of ten concepts, through 20 questions. Eight of the ten concepts are micro-evolutionary, as dictated by natural selection, and there is a lack of items to assess macro-evolutionary understanding. Similarly, Beardsley (2004) utilised essay questions and three multiple choice questions that only assessed microevolutionary concepts; variation, inheritance and adaptation.

The six concepts identified by Shtulman (2006) - variation, inheritance, adaptation, domestication, speciation and extinction were discussed in the literature review. For the current study, these six concepts were selected as they provide a conceptual basis for the understanding of evolution and show a balance of micro-evolutionary and macro-evolutionary concepts. It was possible to identify suitable age-appropriate scenarios for the 6 concepts as they can be simplified (Smith, 2010).

3.6.1.2. Format

Instruments for older children and adults were consulted to decide the format of the instrument to be developed. The Conceptual Inventory of Natural Selection, developed by Anderson, Fisher and Norman (2002) was designed to be used with undergraduate students. Each section began with an example organism and eight multiple-choice questions followed about that organism. There are three example organisms, so a total of 24 multiple choice questions were asked. Beardsley (2004) implemented a similar but much shorter format, using three multiple choice questions as a pre-test and three different questions at post-test with eighth grade students in the United States.

The format decided upon for the instrument developed for this study was to use an example organism followed by six multiple choice questions; each question focussed on one of the six concepts considered by Shtulman as necessary to understand evolution. Multiple-choice questions require the participant to differentiate between their own ideas and other ideas given. Whilst unexpected misconceptions cannot be identified, the multiple-choice format allows answers to be compared between participants (Sadler, 2000).

Multiple-choice tests enable a large number of participants to be sampled in a short amount of time when compared to interviews which have been traditionally used to determine understanding and misconceptions.

Tamir (1971) promoted the use of multiple-choice tests to assess a scientific topic using feasible answers as distractors. The distractors need to be carefully designed by consulting existing research or conducting a pilot study with the opportunity for participants to provide open-ended answers. The potential guessing of answers is a criticism of multiple-choice tests, however this can be reduced if the answers are reasonable and the participant is required to make an educated guess by eliminating the answers they know to be incorrect (Tamir, 1990). If participants do guess correctly, their understanding could be over-estimated and Tamir (1990) suggests that it is necessary to request a justification from participants. The data collected from justifications is a rich source of information about correct and incorrect ideas which can be analysed, as it was in this study. This analysis can then be used to further improve the assessment.

A limitation of multiple-choice tests is that the participants may not interpret the answer statements as the author intended and the opportunity for clarification is limited which may affect the validity of the test (Hodson, 1993). In the current study two pilot phases were conducted to reduce any misunderstanding and during the administration the participants could ask for clarification if necessary.

Another limitation is that pencil and paper tests make demands on the reading and comprehension abilities of the participant (Taber, 1999) which may be more problematic if the vocabulary is novel. During the design of the questions the vocabulary was kept simple,

for example ‘baby’ was used instead of ‘offspring’. During the administration participants that had reading or comprehension difficulties identified by their class teacher had the questions read to them.

3.6.1.3. Questions

Organisms chosen included two plants and seven animals; cactus, kapok tree, duck, giraffe, elephant, hawkfish, curlew bird, polar bear and coral snake. The examples were chosen to be familiar enough that the children would recognise them or a similar organism but not overly familiar (such as a dog) so they would not make assumptions based on specific personal previous experience. Pictures of each organism were provided to assist the participant’s knowledge of the organism and what it looks like. The questions were worded using simple vocabulary to minimise dependency on knowledge of specialised words, which is important in a pre-test (Sadler, 2000).

The alternatives for each question included common misconceptions identified in existing instruments in the literature about the understanding of evolution (Gregory, 2009) as well as the researcher’s prior experience as a biology teacher. The incorrect answers were designed to be plausible so that it was less likely that the correct answer would be chosen only by excluding the other alternatives on the basis of implausibility. Each question was designed to have one or two possible answers so that each participant had to consider every answer, to reduce the chance of random or systematic guessing. For some questions it was essential to have two correct answers: for example an extinction question may require responses for both natural and man-made causes.

A total of nine organism questions, each with 6 multiple-choice questions were designed. Piloting of the questions was necessary to investigate the reliability and validity of the items as well as practical details such as the time required.

Using the Hawkfish as an example the development of the questions and answers will be described for three concepts. The pictures and context were given at the start of the questions. In each case, the correct answer is identified.

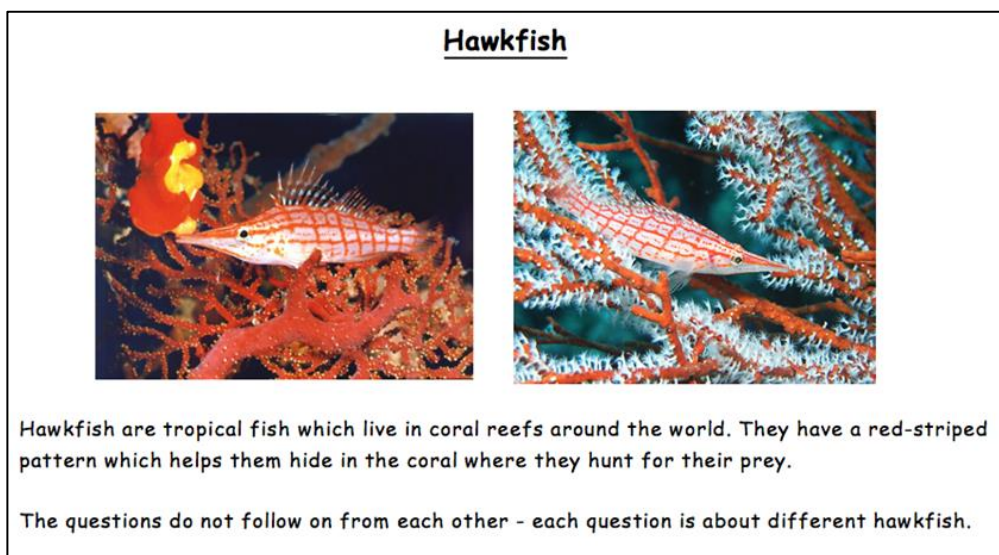


Figure 3.1: The picture and context provided about the Hawkfish

On one coral reef there are 150 hawkfish and a scientist recorded their red markings. What would the scientist have seen?

<input type="checkbox"/>	all the fish would look the same
<input type="checkbox"/>	the fish would all have completely different markings
<input checked="" type="checkbox"/>	there would be some differences between the fish
<input type="checkbox"/>	the red markings might change whilst the scientists are there

Figure 3.2: Variation question about Hawkfish

The first answer is designed to determine whether the participants can identify variation between individuals of the same species they are unfamiliar with. For example, with humans or dogs they would be more likely to acknowledge the differences. The second answer is the opposite and asks the participants to recognise that there will be some similarities.

The fourth answer would be selected if the participants thought that the environment and/or humans had a direct impact and that physical characteristics could be changed in a short period of time.

A male and female hawkfish produce many eggs. The eggs are taken from the coral reef and placed in a fish tank to hatch without any red coral. What will the baby fish look like?	
<input type="checkbox"/>	will be completely white
<input checked="" type="checkbox"/>	will be white with as many red stripes as their parents
<input type="checkbox"/>	will have half as many red stripes as their parents
<input type="checkbox"/>	will be completely red

Figure 3.3: Inheritance question about Hawkfish

The first answer addressed the common misconception that the environment has a direct impact on organisms when they are born. Participants may select this answer if they do not recognise the importance of genetic inheritance.

The third answer implies that an individual at birth is a result of its parents' genetic make-up and the specific environment it is born into. The fourth answer would be a random result that is not affected by genetics or the environment.

A pet shop wants to breed hawkfish to sell them for people to keep in their fish tanks. The hawkfish need to be smaller than they are in the wild. How could the pet shop produce lots of small fish from the existing wild parent fish?

<input type="checkbox"/>	feed the baby fish less so they don't grow as big
<input checked="" type="checkbox"/>	choose the smallest male and smallest female to breed
<input type="checkbox"/>	keep the fish in a smaller tank and they won't grow as big
<input type="checkbox"/>	let the fish breed naturally and they will end up smaller

Figure 3.4: Domestication question about Hawkfish

The first answer and third answers are about the environmental impact of food and habitat availability and ignores the breeding element of domestication. The fourth answer would be selected if the participants thought that humans could not have an impact on species.

The final assessment with all the questions can be found in Appendix A.

3.6.1.4. Pilot phase 1

A sample of 27 children from Years 5 and 6 was recruited from a primary school in Bristol. Each participant completed three randomly assigned organism questions, a total of 18 multiple-choice questions. The participants were assessed in two separate groups in one afternoon. Participants were asked to complete the questions independently but they could ask the researcher questions at any time. It took between 20 and 30 minutes for the participants to answer the questions.

Interviews were conducted the following day with eight randomly selected participants.

Questions about each of the nine organisms were answered at least once by the participants.

The interview involved asking each participant to justify their multiple-choice selections. The researcher asked further questions for clarification when necessary. Their opinions on the style of questions were obtained. All of the participants said they enjoyed answering the questions and there were very few language or vocabulary concerns.

The interview data indicated that children could hold incorrect views even when they had selected the correct answer from the options. It was deemed necessary to request an explanation to complement the information collected through multiple choice.

3.6.1.5. *Pilot phase 2*

A further sample of 30 children from Years 5 and 6 was recruited from the same school in Bristol. The children completed some of the same questions, but were now asked to add a justification for their choice. This increased the time taken for the task and each child only answered two sets of questions, each set about one organism. Most participants took 30 minutes; 15 minutes per question.

3.6.1.6. *Analysis*

The data from all 57 participants were analysed.

Contingency tables were used to analyse the level of agreement between pairs of questions about the same concept. If the two questions are measuring the same concept, it would be expected that each participant answered both correctly or both incorrectly. For example, the participants (n=5) that completed both the duck and giraffe variation questions were compared as shown in Table 3.3. Four out of the five participants either answered both

correct or incorrect; the level of agreement between questions is 80%. Contingency tables were constructed for all 36 organism combinations for the 6 concepts.

Table 3.3: A contingency table for the variation questions for the giraffe and duck (n=5)

		Giraffe variation	
		Correct	Incorrect
Duck variation	Correct	2	0
	Incorrect	1	2

The level of agreement for each of the six concepts was averaged for each organism combination to give a mean level of agreement. The mean scores were consulted to identify which three organisms had the highest level of agreement. Participants were to be allowed 45 minutes to complete and provides three answers for each of the six concepts per participant. The three organisms selected for the final assessment were cactus, curlew and hawkfish.

Table 3.4, shows the percentage of correct answers for each question. The participants scored lowest on the curlew questions with the exception of giraffe speciation. Four out of the six concepts had two correct answers which may explain the lower scores. Alternative scoring for the questions with two correct answers was considered so that credit is given for a part-correct answer. It was decided that participants would only need to select one answer per question which would then be marked as correct or incorrect.

Table 3.4: The percentage of correct answers for each question. Shaded squares indicate there were 2 correct answers.

	Variation	Inheritance	Adaptation	Domestication	Speciation	Extinction
Duck	15	25	15	15	70	10
Giraffe	40	47	13	7	0	57
Cactus	17	25	12	23	75	25
Elephant	22	56	6	6	75	25
Hawkfish	70	23	23	54	31	46
Curlew	12	12	12	6	6	12
Polar bear	37	25	37	12	37	19
Kapok tree	75	50	50	6	73	13
Snake	47	75	56	43	50	62

3.6.1.7. *Final instrument*

The final assessment (Appendix A) that was used in the study consisted of three organisms; cactus, hawkfish and curlew as they had high levels of agreement. These organisms show a range of habitats and the characteristics focussed on can be varied, such as camouflage and beak design. This reduced any potential overlap between questions and ensured that if a participant got all three questions about a concept correct they had a secure understanding as they could apply their knowledge to different contexts and unfamiliar organisms.

The reliability was assessed using the data collected at pre-test and post-test. The Cronbach alpha coefficient was 0.5 at pre-test and 0.6 at post-test which is acceptable for a newly created measure (Nunnally, 1978).

The control group had not received any teaching and as such their pre-test and post-test data was used to determine the test retest reliability to see if the test results are consistent over

time. There was a strong positive correlation between the pre-test and post-test scores, $r = .69$, $n = 73$, $p < .001$.

Two of the assessments taken at pre-test were existing standardised instruments. The validity of newly created instruments can be investigated by correlating the scores with an existing standardised instrument that could be predicted to measure similar constructs. As such, the evolution assessment scores and the science reasoning score at pre-test were correlated to check the validity of the assessment. Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity and homoscedasticity. The two variables had a moderate positive correlation, $r = .39$, $n = 111$, $p < .001$.

3.6.1.8. Administration procedure for final instrument

Participants were given a paper booklet containing the multiple-choice questions about the three organisms. The researcher orally explained that they needed to read the information provided and select the answer they thought was correct. If they were unsure, they were told to select the answer they thought was the best answer and to give a justification. They were encouraged to think carefully about each question and not to leave anything blank.

Participants could request the questions to be read to them if they were unsure of the questions.

The pre- and post-tests were administered to participants in their class groups with absent participants being assessed in smaller groups on subsequent days.

The assessments were anonymised and the multiple-choice questions were marked by the researcher using the prescriptive mark scheme created by the researcher.

3.6.2. Science reasoning task – Volume and Heaviness

The Science Reasoning Tasks (NFER, 1979) were developed at King's College, London as part of the assessments for the Concepts in Secondary Maths and Science (CSMS) study which was discussed in the Literature Review (section 2.9.1). They replaced the traditional interview method which was time consuming as one-to-one time was required with each child. The tasks were developed to be used with whole classes and take around 50 minutes to complete. The volume and heaviness task was selected for this study as it covers a wide range of Piagetian levels (1-3A) and has been used in similar studies with different topics (Adey and Shayer, 1994). Both the internal consistency (.78) and the test re-test (.84) correlations were found to be high (Shayer, Adey and Wylam, 1981) for the Volume and Heaviness task indicating good reliability.

During the development of the tasks the researchers assigned a Piagetian level (1, 2A, 2B etc.) to each question and the marking guidelines provide instructions on how a level is assigned to each child depending on the questions answered correctly. The scoring is cumulative; they must show they attain the positive criteria for the earlier stages to be assigned a higher one.

The tasks were chosen for the study as a measure of cognitive development. The tasks were purposefully de-contextualised to allow the cognitive development of all participants to be assessed regardless of which group they belonged to. If the tasks had a basis in evolution,

electricity or any other scientific topic the results might be biased towards the participants that had a better understanding of the topic. Therefore a task not requiring any content knowledge was selected.

The first two questions are provided in Figure 3.5 and the instructions detailed below.

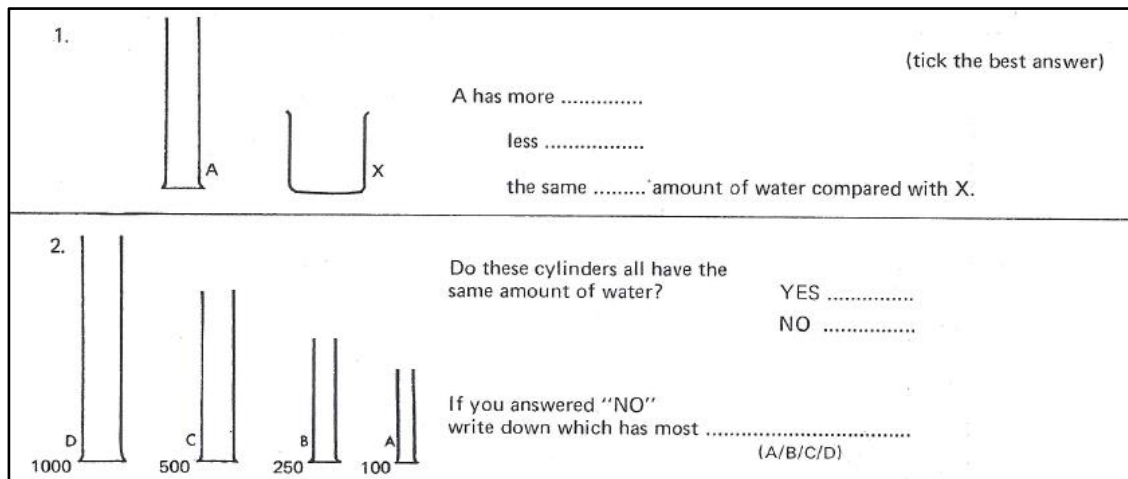


Figure 3.5: First two questions from the Volume and Heaviness science reasoning task taken from NFER (1979).

Question 1: A is the 100cm³ measuring cylinder. X is the 250cm³ beaker. Fill A at the tap and emphasise that it is full. Pour into X. Refill A. Put A and X alongside each other so they can be seen. Ask ‘does A have more, less or the same amount of water compared with X?’

Question 2: Fill A at the tap. Pour into D. Refill A and pour into C. Refill A and pour into B. Refill A. Put all 4 together in line so they can be seen. Ask ‘do these cylinders all have the same amount of water, if you answered no, write down which has the most.’

3.6.2.1. Administration procedure

The test was orally administered by the researcher following the script and practical instructions provided by the authors. Each participant had their own answer sheet and the participants were encouraged to think for themselves.

The group sizes varied between 10 and 16 participants depending on the room availability at the schools.

The assessments were anonymised and marked according to the prescriptive mark scheme which assigns a Piagetian level (1-3A) to each participant.

3.6.3. Wechsler Intelligence Scale for Children (WISC) subtest:

Similarities

The Similarities subtest seeks to assess children's verbal reasoning and their ability to conceptualise and categorise items, some of which might be known from memory whereas others require reasoning to categorise them. The items are from a sub-test of the Wechsler Intelligence Scale for Children (WISC), a test validated for a UK sample, which assesses children's intelligence across the age range of 6 to 17 years old. The items that will be used in the current study are from a core Verbal Comprehension subtest.

The Similarities test has 1 practice item followed by 22 questions and has been adapted from an oral test to a written one for the current study. The participant is presented with a written stimulus that requires a written response. The participant is presented with two words that represent common objects or concepts and is asked to describe the similarities between the

pair of items. For example, the objects are apple and banana and the expected answer is '*they are both fruit*' and would score 2 points. One point would be scored for a less pertinent classification such as '*they are both food*'. A score of 0 would be assigned for a description that does not apply to both objects or a description of the differences. There is a set of answers with scores in the WISC manual which was followed.

The Similarities produces a single raw score (maximum of 44) as well as percentile rank to indicate the child's ability, compared to a norm group. The items show a reliability coefficient of .86 for an age group of 10 years old. The average corrected stability coefficient for Similarities is good (.88) (Wechsler, 2003).

3.6.3.1. Administration procedure

The items were presented on paper and the test was carried out as a group in silence after the researcher had discussed the practice item. The group sizes were between 15 and 28 participants. The assessment took around 20 minutes and the participants could take the time they needed up to a maximum of 30 minutes.

The assessments were anonymised and then scored by the researcher using the scoring manual provided in the technical manual.

3.7. Intervention

Intervention sessions for evolution and electricity were designed for use in the study. The electricity intervention was based on the published *Let's Think through Science* programme

for year four children and adapted for use with Year 6 children. The researcher had taught the Year 4 programme in a previous study and was familiar with what it entailed. The National Curriculum was reviewed before designing the sessions and care was taken to ensure the National Curriculum was being covered and the activities were relevant for the older age group.

The evolution intervention design is detailed in the following section.

3.7.1. Evolution intervention design

As discussed in the literature review the intervention was designed using the cognitive acceleration principles to promote conceptual change and was to include a session for each of the six concepts identified by Shtulman (2006); variation, inheritance, adaptation, speciation, extinction and domestication.

The *Let's Think through Science* programmes for younger children were consulted initially to determine if there were relevant sessions. Existing schemes of work purchased by schools were examined but the lessons were very much focussed on the National Curriculum statements and there was very little further knowledge, in particular inheritance, speciation and domestication were almost completely absent. The intervention sessions were written by the researcher using their knowledge of the concepts and previous experience as a science teacher. The conceptual content was discussed with a secondary school biology teacher and the activities were checked by a primary school teacher to determine their age appropriateness.

The six lessons followed the order of the six concepts; variation, inheritance, adaptation, speciation, extinction and domestication. This order is meaningful in that it is a reasonable assumption that it would be necessary to understand variation to be able to decide which characteristics are inherited. Adaptation has its basis in the importance of inherited characteristics. Speciation and then extinction follow as the macro-evolutionary concepts which look at the longer term ideas. Domestication was the final session as the human involvement in the preceding microevolutionary concepts may detract from the naturally occurring process if placed earlier. Each session has a conceptual focus but this does not exclude discussion of related concepts: for example, variation is a concept discussed in all lessons as it relates to all other five concepts.

The organisms presented in the assessment were completely absent in the intervention to measure the understanding of the concepts rather than learning about the specific organisms. Organisms were selected to be familiar enough but not so much that they could repeat answers they had previously heard, irrespective of whether these were correct answers or misconceptions. Humans were sometimes used as an example in the concrete preparation section as this was relatable and the participants often had questions about their own experience or family history.

3.7.1.1. Piloting the intervention sessions

All six sessions were piloted with a group of 15 participants from School 2 in July 2016. After the first session changes were made and each session was delivered again to a different group of 15 participants from School 2 to trial the changes and further improve the intervention sessions.

Changes included removing examples that the participants had been over familiar with or adding more flexibility to the tasks to allow for challenge. Some of the pictures used caused confusion, especially the plant examples where the presence of fruit induced answers about seasons or age rather than inheritance and reproduction.

More comprehension and written tasks were added so that participants were required to commit to their answer before they shared their ideas, ensuring that cognitive conflict was induced. Written tasks also allowed better records to be kept of their thinking.

3.7.2. Description of sessions

The intervention sessions will be described linking the activities to the cognitive acceleration principles and these are and summarised below. The types of questions asked in the sessions are italicised. The cognitive acceleration pillars were summarised in Table 2.2.

3.7.2.1. *Variation session*

The aim of this session was to introduce the concept of variation and highlight the fact that within-species variation exists. Important vocabulary used throughout the intervention was introduced in this session.

Pillar of CA	Description
Concrete preparation	Students were asked to discuss their understanding of the word ‘variation’ and the ideas were fed back to the group. They were

asked to give examples where possible. Most examples given showed variation between species and the differences within species were discussed using concrete examples that the students were already familiar with.

What do you understand by 'variation'? Can you give me an example you have seen? Do all people look the same?

Cognitive conflict
and social
construction

In groups the students were provided with a picture of a group of organisms from the same species (e.g. lions, pine trees, fish). Different groups were given different organisms. They were asked to discuss the similarities and the differences that they could see within their groups and then feed back to the whole group.

Can you see all variation? What about behaviour or where they live? Are plants all the same? Does anyone have any other suggestions to add?

Cognitive conflict
and social
construction

A discussion was encouraged about the causes of variation and the terms 'genetic' and 'environmental' were introduced using the examples given in the previous activity. The groups were then given a set of cards that had various characteristics about animals and plants and they were asked to group them into genetic or environmental causes. They were not told there could be a third category of 'both' to induce cognitive conflict. Some groups

created this category themselves and others recognised its necessity during the feedback discussion.

Can you tell me why you put that in that group? Are there any other examples you can share? Why do you disagree with that grouping?

Metacognition

After the activities time was left to reflect on what they had learnt. The new vocabulary was re-capped and a discussion was facilitated about what they had found difficult and which new ideas they had found useful to help them understand.

Did any of the activities today make you think differently? What was the most difficult idea to understand? In your group can you give an example of when someone else's idea was useful?

3.7.2.2. Inheritance session

The aim of this session was to make the link between variation and inheritance: only genetic variation is inherited and any changes due to environmental pressures will not be found in offspring.

Pillar of CA

Description

Concrete preparation Students were asked to discuss 'why you are the way you are' and the ideas were fed back to the group. A discussion was

facilitated around ‘parents’ and a brief introduction about reproduction and the inheritance of genes was given. The term ‘offspring’ was introduced.

Do you look/act the same as your parents? Why do you look similar to your siblings? Do all species give birth to babies? How do plants reproduce?

Cognitive conflict
and social
construction

In groups the students were provided with a picture of an organism and its offspring. Different groups were given different organisms. They were asked to discuss whether the offspring and adults were similar and/or different. Each group then presented their organism to the other groups and they had the opportunity to ask questions.

Why might they look different? What was inherited by the offspring? Does anyone have any other suggestions to add? Does anyone disagree with what has been said?

Cognitive conflict
and social
construction

The genetic and environmental causes of variation were reviewed and the groups were asked to list examples using the organism given in the previous activity. They then had to categorise what they thought would be inherited by the next generation. Challenging examples such as ‘personality’ were introduced to create cognitive conflict. A discussion was facilitated around inheritance and the fact that any environmental changes will not be passed on to the offspring.

Can you tell me why you think that? Are there any other examples you can share? Why do you disagree with that suggestion?

Metacognition After the activities time was left to reflect on what they had learnt. The new vocabulary was re-capped and a discussion was promoted about what they had found difficult and which new ideas they had found useful to help them better understand.

Did any of the activities today make you think differently? What was the most difficult idea to understand? In your group can you give an example of when someone else's idea was useful?

3.7.2.3. *Adaptation session*

The aim of this session was to explore how adaptations arise in a population as a result of the existing variation and differential rates of survival.

Pillar of CA	Description
Concrete preparation	Students were given a picture of a garden frog in groups and were asked to label any characteristics (seen or unseen) that made the frog well adapted to its habitat. The term habitat was defined in the task introduction and the organism was well known to the

students. The groups then fed back attempting to give a different characteristic each time.

What do you understand by 'habitat? Can you describe where this frog might live? Can you suggest a behavioural adaptation?

Cognitive conflict
and social
construction

In groups the students were provided with a picture of an aquatic habitat where the frog might live. They were also given a pot containing paper frogs of various shades of green and with different patterns on. They had to select 10-15 frogs that they thought would survive in the habitat. Individually they wrote an explanation of the choices they made. After they had committed to their written explanation their ideas were discussed and the importance of variation reiterated.

Can you describe the variation between your 10 frogs? Would all your frogs be the same?

Cognitive conflict
and social
construction

The groups were given a picture of a different habitat (habitat 2) which was lighter in colour and told that the 10-15 frogs in the original habitat (habitat 1) moved to live in habitat 2 and reproduced. In their groups they had to choose 10-15 frogs from the pot to represent the offspring in the first and second generation of frogs born in habitat 2. Individually they wrote explanations for their choices and these were discussed as a whole group. Any

mention of intentional or non-random colour changes were challenged.

Can you tell me why all of your generation 2 are not all exactly the same colour? Why are there now a greater number of lighter frogs? Does anyone disagree with that explanation?

Metacognition After the activities time was left to reflect on what they had learnt. The new vocabulary was re-capped and a discussion was had about what they had found difficult and which new ideas they had found useful to help them understand.

Did any of the activities today make you think differently? What was the most difficult idea to understand? In your group can you give an example of when someone else's idea was useful?

3.7.2.4. Speciation session

The aim of this session was to highlight what we know about the evolutionary timeline using fossils and the tree of life to show all species have a common ancestor.

Pillar of CA	Description
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Concrete preparation	In pairs the students were asked to discuss two questions 'how long ago did the first living organism appear on Earth?' and 'how
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many species do you think there are now on Earth?'. After their ideas were fed back they sorted 11 evolutionary events (first fish, first mammal etc.) into a timeline and a discussion was facilitated about how the earliest living organisms were much simpler than the complex organisms that exist today.

What do you notice about the organisms that were first on Earth?

Can you tell me why you placed that organism before this one?

Cognitive conflict
and social
construction

The evidence we have about the evolutionary timeline was discussed and fossils were consistently mentioned by the students. They were given images of the limbs five different mammals (human, cat, bat, whale and horse) and asked to discuss the similarities and differences they could see in the skeletons and what this tells us about relationship between the species.

Why might the bones be similar? Why might some of the bones be different? Does it matter that they live in different environments?

Cognitive conflict
and social
construction

Each group was given a colour copy of the Open University tree of life to explore and the online version was projected onto the whiteboard. They were familiar with creating their own family tree so this was used to describe how the tree of life worked. In their groups they were then asked to discuss what the branches symbolised and to find examples of closely related organisms where they could give examples of similar characteristics.

Can you tell me why you think ___ and ___ are closely related? Do all the species on the tree still exist? Why do you disagree with that suggestion?

Metacognition

After the activities time was left to reflect on what they had learnt. The new vocabulary was re-capped and a discussion was had about what they had found difficult and which new ideas they had found useful to help them understand.

Did any of the activities today make you think differently? What was the most difficult idea to understand? In your group can you give an example of when someone else's idea was useful?

3.7.2.5. Extinction session

The aim of this session was to highlight that a much greater number of species have become extinct due to maladaptation than the number of species that currently exist, regardless of human intervention.

Pillar of CA

Description

Concrete preparation

Students were asked to discuss their understanding of the word 'extinction' and to give an example if they could of an organism that had become extinct. In the discussion this was linked back to

the adaptation session and what aids survival and what may cause extinction.

What do you understand by 'extinction? Why did that organism go extinct? What about organisms in the zoo?

Cognitive conflict
and social
construction

In groups the students were provided with a picture of an extinct organism along with a factual paragraph with relevant information about its extinction. The groups were asked to use their knowledge of adaptation to explain why their organism became extinct. They had to present their ideas to the whole group as a presentation and the other groups asked them relevant questions.

Why did the environment changing have such an impact? Does anyone have a question to ask? Do you disagree with that explanation? Does anyone have any other suggestions to add?

Cognitive conflict
and social
construction

Examples of endangered organisms were given, many of which were at risk of extinction due to human activity. A discussion was facilitated about how humans are increasing the rate of extinction but most organisms have become extinct before humans had any influence. The groups were asked to discuss conservation and how the endangered organisms could be better protected from extinction.

Why are humans hunting that species? Can we slow deforestation? Are extinctions only cause by human activity?

Metacognition After the activities time was left to reflect on what they had learnt.
The new vocabulary was re-capped and a discussion was had about what they had found difficult and which new ideas they had found useful to help them understand.

Did any of the activities today make you think differently? What was the most difficult idea to understand? In your group can you give an example of when someone else's idea was useful?

3.7.2.6. Domestication session

The aim of this session was to discuss the differences between domestication and adaptation in natural settings and for them to be able to describe the process of domestication using examples.

Pillar of CA	Description
Concrete preparation	Two pictures of dogs were shown to the whole group, a small Chihuahua and a large Dalmatian and the students were asked to discuss whether the dogs were the same species based on what they had learnt in previous sessions.

What defines a species? Could those two dogs breed with each other? Why do you think they are different species?

Cognitive conflict
and social
construction

In groups the students were provided with a picture of a wolf and were told that all modern dog breeds have been domesticated from a wolf. They were asked to discuss how and why this may have happened before sharing their ideas with the group.

How could you change the size so much? Why would humans have done that? Would the dogs still survive in the wild? What problems might this cause in the long-term?

Cognitive conflict
and social
construction

Each group was given an information sheet with four cows and four bulls listed. Detail was given about their meat and/or milk production and their habitat requirements. Each group was given a different requirement such as ‘a farmer in a hot climate requires many cattle that produce a lot of meat’ and they had to describe how they would proceed to produce a herd of cattle fitting the description.

Is that the only bull that would be suitable? Are there any other examples you can share? Would only one generation of breeding be enough? Could you make the process quicker?

Metacognition

After the activities time was left to reflect on what they had learnt. The new vocabulary was re-capped and a discussion was had about

what they had found difficult and which new ideas they had found useful to help them understand.

Did any of the activities today make you think differently? What was the most difficult idea to understand? In your group can you give an example of when someone else's idea was useful?

The four electricity sessions are described in Appendix B.

3.8. Ethical considerations

All stages of the current study received ethical clearance from the Central University Research Ethics Committee (Appendix C). A fieldwork risk assessment was approved and the researcher possesses Disclosure Barring Service (DBS) clearance which was presented to all schools upon arrival. The research adhered to the British Educational Research Association guidelines (BERA, 2011)

The head-teachers were contacted via letter (Appendix D) and provided with comprehensive information about the study including examples of what would be sent to parents. Once permission was obtained, parents were sent an information letter with a consent form (Appendix E) asking them to explain the process to their child. Consent was gained from the parents on behalf of the children as they were under the age of 16. This study utilised opt-out consent and participation was entirely voluntary.

At the start of the study the researcher explained the nature of the research to the participants and answered any questions they had. They were told that they have the right to withdraw at any time by simply informing the researcher.

Care was taken to arrange times with teachers so that minimal disruption was caused to the usual school day. The interactions between the researcher and the participants were carried out in a professional and sensitive manner ensuring the children were comfortable at all times. The assessments and teaching sessions were all carried out in groups, in open and accessible areas of the school.

The data collected for this study was securely stored on the researcher's laptop in a password protected file. All the data was anonymised and ID numbers were given so individuals cannot be identified from the data or the report.

3.9. Analyses

This section describes an overview of how the data collected were analysed to address each hypothesis. The results are presented in the subsequent chapters.

The first hypothesis states that explicitly teaching the six evolutionary concepts will result in conceptual change from a transformational to a variational understanding. This effect is deemed to be specific to the concept taught and not to be apparent in another scientific concept, namely electricity.

The first hypothesis was addressed in three ways during the analysis.

The data collected during the intervention sessions is described to show how participants responded to the tasks and examples are provided to show the transformational and variational ideas that were shared during the sessions. The data is qualitative and based on field notes and the participants' written work collected during the sessions. The quantitative data from the multiple-choice answers at pre and post-test were analysed using Analysis of Covariance (ANCOVA) as the data were normally distributed and did not violate any of the assumptions. The evolution assessment post-test scores acted as the dependent variable, the group membership as the independent variable and the verbal reasoning score as the covariate.

The data from the written justifications were analysed in two ways; firstly the quality of the answers was scored according to a created protocol and secondly the frequency of scientific vocabulary was compared at pre and post-test.

The second hypothesis is that, due to the nature of the teaching programme, which is based on the use of cognitive conflict, discussion and reconstruction of the pupils' solutions to problems, there will also be a measurable effect on the pupil's cognitive development.

The second hypothesis was analysed using Analysis of Covariance (ANCOVA) as the data were normally distributed and did not violate any of the assumptions. The science reasoning assessment post-test scores acted as the dependent variable, the group membership as the independent variable and the verbal reasoning score as the covariate.

3.10. Chapter summary

This chapter provided a detailed description of the current study's methodology including the aims, hypotheses, research design and schedule, participants and recruitment, assessment measures, intervention design and ethical considerations.

An intervention study was conducted to investigate the effectiveness of an evolution intervention designed in the study. The experimental design randomly allocated participants to one of three groups; the evolution group, the electricity group or the unseen control group. The study employed pre-tests and post-tests to evaluate the effectiveness of the intervention and the participants were 114 Year 6 children from two schools in England.

The findings will be discussed in the following chapters. Chapter 4 will examine the data that contributed to the first hypothesis and Chapter 5 will look at the second hypothesis.

Chapter 4: Findings from the evolution intervention

This chapter presents an evaluation of the evolution intervention and addresses the first hypothesis.

The first hypothesis states that explicitly teaching the six evolutionary concepts will result in conceptual change from a transformational to a variational understanding. This effect is deemed to be specific to the concept taught and not to be apparent in another scientific concept, namely electricity.

The chapter has three sections, each examining different data that contribute to the first hypothesis.

The first section provides a detailed evaluation of each of the six intervention sessions describing the activities, the participants' reaction and how their questions were answered to focus the lesson on the concept. Qualitative comments are made about the evidence of transformational or variational thinking shown during the sessions.

The second section details the empirical findings examining the effects of the intervention on the understanding of evolution using the participants' multiple-choice answers from the evolution assessment.

The third section examines the written justifications given by participants at pre- and post-test to determine whether they can be identified as transformational or variational thinkers. The justifications were scored according to a protocol to examine whether their scientific

understanding improved over time. The frequency of correctly used vocabulary at pre- and post-test were compared to see whether the exposure of new scientific vocabulary during the intervention sessions had an impact.

4.1. Intervention evaluation

This section aims to provide a clear overview of what the intervention sessions entailed and a commentary on how the consistency of session delivery between groups and schools was maximised. Throughout all sessions care was taken to focus on the evolutionary concepts and examples are given to show how this was done so that the fidelity of the intervention was maintained.

Each session will be described and detail provided about the aim, vocabulary introduced, activity progression. Examples of challenging questions asked by the participants are given with a commentary of how these were dealt with. The school context is discussed to give relevant examples of when the responses from participants was varied. Finally a brief conceptual analysis to show examples of transformational or variational thinking, if they occurred in the session.

During the intervention sessions data were collected as field notes, written answers from the participants and photographs of group work. The questions asked by the participants and their discussions were recorded in field notes taken after the session had ended and cannot be attributed to a specific participant as they were written as group summaries.

4.1.1. Variation session

The aim of this session was to introduce the concept of variation and highlight that there is within-species variation.

4.1.1.1. Vocabulary introduced

Variation was defined in the initial activity of the session and discussed throughout, to include differences between or within species.

Species was introduced in this session as it has a significance throughout all the sessions.

Using it whenever appropriate and reminding the participants to use it helped to reinforce its meaning.

Organism was introduced as a scientific word that can be applied to both plants and animals as most participants were using animals to cover all organisms.

Genetic and *environmental* were terms used to categorise the cause of variation. As most participants had heard of these words it was important to define them within the context of variation.

4.1.1.2. Progression through activities

The participants were asked to define variation at the beginning of the session. They discussed it in their groups and then fed back to the whole group. The ideas suggested by the participants are summarised in Box 4.1.

a word for change
small changes between things
same things but slightly different
musical variation
different types of jumper (with a hood, with a school badge)
different types of leopard (snow, clouded)
there are different types of bird

Box 4.1: Summary of suggestions from participants for variation definition

All four intervention groups suggested that there is variation between living organisms but all the suggestions were about interspecific (between species) and not intraspecific (within species) variation. Whichever organism the group suggested was used to focus their attention on intraspecific variation. To give an example, the participants that suggested ‘different types of leopard’ were asked whether all types of leopard were one species, providing the opportunity to define *species* and narrow the discussion towards intraspecific variation. Whenever possible, they were shown that *type* could be replaced by *species* in their variation definitions.

In one group the discussion stalled as the participants were struggling to identify variation within the example they suggested (blackbirds) and said they all looked identical. They were asked whether all the individuals would have exactly the same song, or whether they would be equally good at nest building, in order to provide examples of variation beyond what can be seen.

The next activity built on the intraspecific variation idea and the participants were given a picture of organisms from the same species and asked to discuss the similarities and differences between the individuals. Each group had a different organism, examples are

shown in Figure 4.1 and were chosen to represent a range of organisms including both animals and plants.



	Similarities	Differences
Zebra	eat the same food have four legs have tails overall colour	stripe pattern behaviour gender size
Pine trees	type of leaves live in the same environment need sunlight all have roots	height age number of leaves shades of green

Figure 4.1: Example organisms and answers given by participants in variation discussion

Each group shared their ideas about their organism with the whole group and the other groups added examples when appropriate. The discussion was focussed on the differences to maximise the likelihood that the participants could identify variation within their species. Some of the groups found it hard to identify the variation within the species pine trees as the individual trees looked very similar and they could not use behavioural examples. A discussion was facilitated about how it is important to recognise variation within all species, including plants and not just animals.

They were asked what caused the variation within the species using the examples discussed by the groups. All the groups suggested that parents pass things on and this was defined as *genetic* variation. Most of the participants were familiar with the word *genetic* and connected it with their family. Using height or size prompted them to think about the environment and suggestions were given such as 'it depends on how much the zebra ate'.

The participants were given a set of cards with a variety of characteristics and asked to discuss whether they were caused by genetics or by the environment. The categorisation created by two groups can be seen in Figure 4.2. As the groups were discussing each characteristic, many of them asked what they should do when they cannot decide or when it is caused by both genetics and the environment. Some groups were taking a dichotomous approach and were prompted to think about weight and asked targeted questions about how weight is dependent on both genetics and diet as it is a relatable example.

The aim of the discussion was to focus them on the idea that some characteristics are genetically inherited as this idea will be needed in the next session, but not to necessarily ensure the groups achieved the correct categorisation.

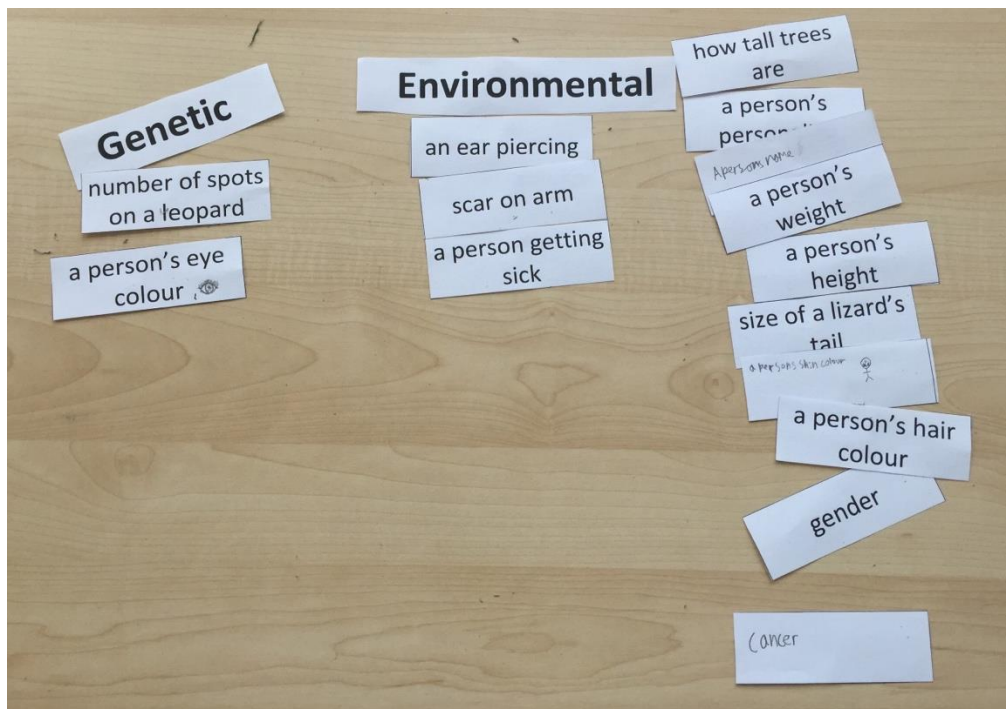
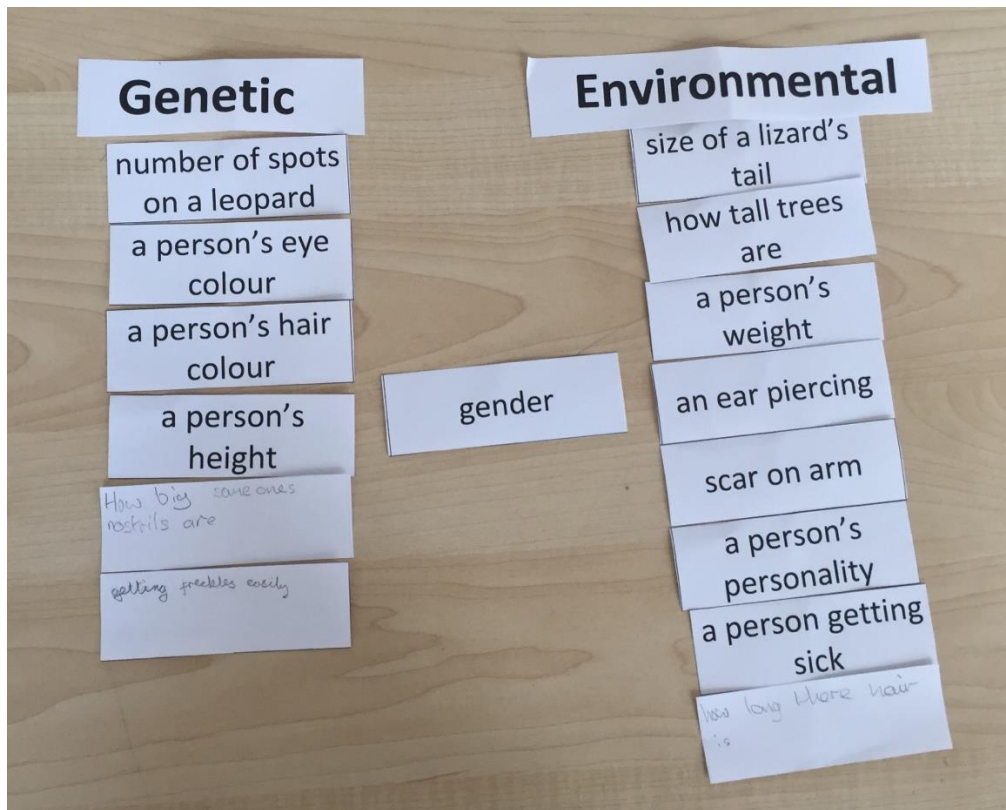


Figure 4.2: Two groups' responses to the variation sorting activity

In the final discussion participants were asked to reflect on the session. They used the opportunity to ask further questions about the lesson content, particularly about their family

histories and inheritance of specific characteristics, which distracted from the metacognition element of the lesson. Wherever possible the questions were answered by asking them to think about what they had learnt. If this was not possible they were asked to write their questions down so they could be answered in a future session if relevant.

4.1.1.3. Challenging questions

In the sessions there were questions posed by participants that were challenging to answer or that did not fit with the aim of the session. Examples of these questions are shown in Box 4.2.

If a family member has cancer does that mean I will get cancer?
If a pregnant lady swallowed an earring would the baby have pierced ears when it is born?
But a person can change their gender so it must be caused by the environment?
Why does my sister have darker skin than me?
Do plants have genetic information?

Box 4.2: Examples of questions asked in the variation sessions

The questions asked could often be answered in a way that re-focused the participants on variation. For example, when asked about cancer they knew that some cancers could be caused by environmental factors (smoking, sunlight etc.) and others were more prevalent if there was a family history. For questions about inheritance they were told that they would look at that in the next session so their question would be answered then.

4.1.1.4. School context

In school one the ethnic diversity was higher and the discussions had a greater focus on race and skin colour. In school two there were several questions about gender and whether changing gender was genetic or environmental. They mentioned they had talked about being

transgender in a recent assembly. It was important to utilise the examples raised in regards to variation as they were relevant to the participants. For example, skin colour could be related to genetic variation by comparing a child's skin colour to their parents but also highlight the effect of sunlight in the environment.

4.1.1.5. *Conceptual analysis*

Transformational views were noted when participants struggled to identify variation between organisms of the same species. For example when they thought all blackbirds or pine trees were identical. This view was given by over half the groups during the session.

However, whether they see variation as relevant to evolution was not apparent in this session as the aim was to establish that variation exists and future sessions would determine whether variational views are present.

4.1.2. *Inheritance session*

The aim of this session was to make the link between variation and inheritance: only genetic variation is inherited and any changes due to environmental pressures will not be found in offspring.

4.1.2.1. *Vocabulary*

Inheritance was defined as receiving genetic information from parents. Some participants had heard the term being used to refer to possessions being inherited after someone has died so it was important to define the term within a scientific context.

Reproduction was introduced as a simple understanding of this term was needed so that the participants could understand how genetic information is inherited and where it comes from. The picture shown in Figure 4.3 was given to the group and discussed. They were told that females have egg cells and males have sperm cells that contain genetic information and during fertilisation the genetic information is combined to produce offspring. Asexual reproduction was not discussed.

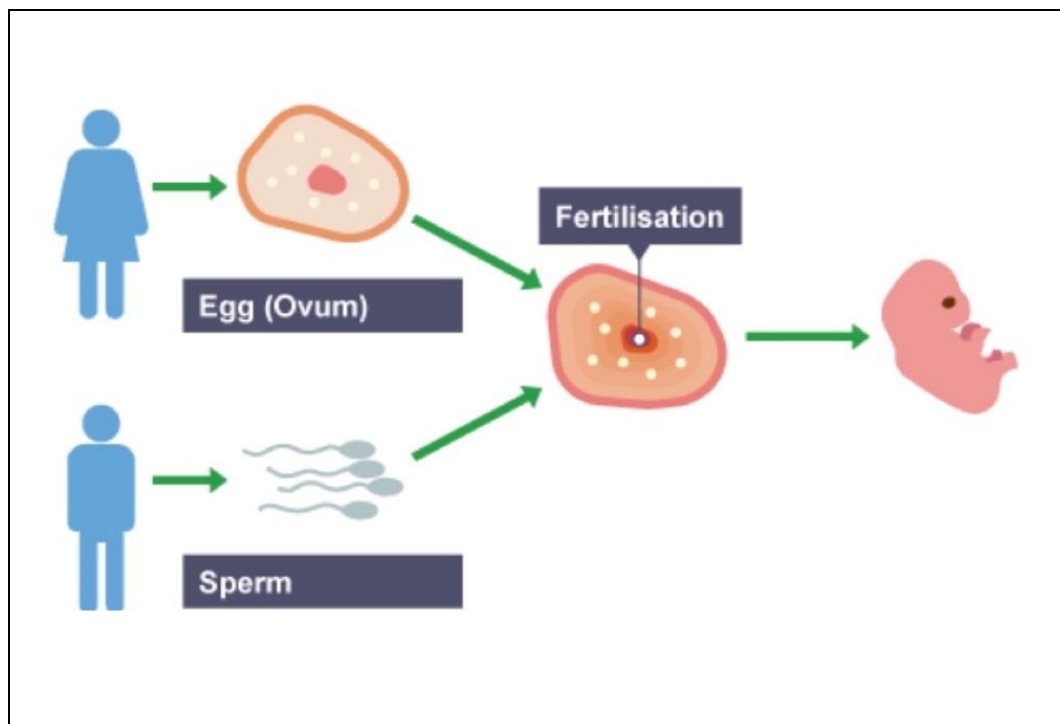


Figure 4.3: Reproduction diagram given to participants

Offspring was a term which needed to be introduced as the participants were using ‘baby’ to refer to the young of most species. Examples were given to demonstrate that this isn’t always appropriate, for example with plants. Offspring was introduced as a term that refers to young of any species.

4.1.2.2. *Progression through activities*

The participants were asked why they are the way they are. They discussed it in their groups and the suggestions were fed back to the whole group. The ideas suggested by the participants are summarised in Box 4.3.

eye colour from my Dad
height of parents
inherit genes
things passed down from family
where you live affects things
personality changes around friends


Box 4.3: Summary of suggestions from participants about why they are the way they are

In all the groups, suggestions were made about their family and genetic causes as well as indications that the environment has an impact. Some participants used specific examples that were used in the previous session and referred to genetic and environmental variation. Wherever possible the participants were asked to identify whether their suggestion was genetic or environmental, reinforcing the vocabulary from the variation session. The discussion was moved on to focus on what is genetically inherited. The simple introduction to sexual reproduction was given as shown in Figure 4.3.

The participants were given a picture of an organism with their offspring. The plant examples raised questions about how plants reproduce and the idea that plants had male and female parts was new to most of the participants, which was surprising as plant reproduction is found in the science curriculum for Year 3 and Year 5. Figure 4.4 shows the questions the participants were asked about the organism they had been given and the aim was for them to

identify that offspring often look different to adults but will be similar when they are adults themselves.


Geese



1. Do the offspring look like their parents? Give a reason for your answer.
 No because they aren't fully grown yet.
 They're the same shape but not the same colour.

2. Will they look similar or different once they are adults? Give a reason for your answer.
 Yes because they're the same species and they have their parents genes.

Tomato plant



1. Do the offspring look like their parents? Give a reason for your answer.
 They can but in this situation ~~no~~ They don't
 Because they develop things as they get older

2. Will they look similar or different once they are adults? Give a reason for your answer.
 Different because they develop fruit but when they are a seed or just a few
 leaves they have no fruit / They will look different because they can grow
 fruit in different places

Figure 4.4: Example answers given by participants in offspring task

Most participants recognised that offspring are smaller and can look quite different to their parents, the stronger answers included examples of variation that would exist amongst the

adults despite them looking similar which demonstrated they were using of knowledge from the variation session.

Using their organism, the participants were asked to write down characteristics and identify them as genetic, environmental or a combination. They were then asked to discuss which of the characteristics they thought the offspring would inherit. Most participants recognised that the genetic characteristics would be passed on and the environmental ones would not.

Characteristics caused by both genetics and the environment caused them some difficulty as they identified that it depended on whether the environment would be the same for the offspring as it was for the parent. Humans were discussed as an organism that cares for their offspring for a long time compared to many species so the environment that the parent creates may have a greater impact on characteristics like personality and weight.

The reflection section was more effective than in the variation session as participants had remembered the types of questions that would be asked. Many participants said they had found the idea that not everything was inherited from parents a difficult idea as they had assumed everything was passed down. Wherever possible they were asked to give examples of ideas they had found difficult during the session.

4.1.2.3. Challenging questions

This session generated many questions about the participants' own features and characteristics including why their eye colour and hair colour was different from their parents; examples are given in Box 4.4.

Why do I have blue eyes but neither of my parents do?
Why does my sister have darker skin than me if we are both mixed race?
How do I know what my future children will inherit from me?
Do we pass on diseases to our children?
Can we choose what is inherited so we can choose whether a baby is a boy or a girl?
How is DNA used to find criminals?

Box 4.4: Examples of questions asked by participants in the inheritance sessions

To answer these questions scientifically would require knowledge of recessive alleles, which the participants were unlikely to have and it would be beyond the scope of the intervention. They were told that some inherited characteristics were hidden in some people but could show up in others, therefore skipping a generation. The participants were also told that they would learn more about inheritance when they started secondary school which alleviated their need to know instantly which was distracting from the aim of the session.

The questions about choosing characteristics or controlling what is inherited were addressed in an ethical manner by asking the participants why that would not be a good idea. If they struggled to suggest reasons they were guided back to why variation is important or what might happen to the population if all parents chose to have a girl.

DNA was a term that some participants used as they said they had heard it in films or TV and they used phrases such as 'isn't it in your blood'. These questions were answered by saying that DNA was found in all your cells but only the DNA in the egg and sperm cells were passed on.

4.1.2.4. School context

In school 2 they had recently learnt about reproduction and puberty in a healthcare lesson but had not covered reproduction in a scientific context. Their questions were in relation to what they had been told in the healthcare lesson. Some of the participants in school one struggled to maintain their maturity which distracted from the session at times. Using non-human examples helped to focus them back on the topic as they found it less amusing.

4.1.2.5. Conceptual analysis

The importance of variation was discussed by many of the participants in this session and they realised that this would affect the subsequent generation. As in the variation session there was no evidence of the variational view of inheritance as this involves an understanding of adaptation.

During the sessions there was little evidence to suggest the transformational view of inheritance according to which only beneficial traits are inherited; discussions about inherited diseases demonstrated that characteristics can be inherited despite the negative consequences.

4.1.3. Adaptation session

The aim of this session was to explore how adaptations arise in a population as a result of the existing variation and differential rates of survival.

4.1.3.1. Vocabulary

Habitat was a term that many of the participants had heard before but they were defining it more generally (e.g. the whole country they are found in) than required and so they were told it was an area that a specific species lived in. Different species that live in close proximity to each other will have a slightly different habitat.

Adaptation was discussed as a process rather than the product but many of the participants used the term to refer to a physical characteristic as an adaptation as this was what they had been taught before. For example, they suggested an adaptation could be camouflage, or the streamlined shape of a fish, rather than adaptation being the process that led to those features.

Survival was a word that most participants seemed familiar with but it was defined within the context of the lesson as being about the chances of survival during an organism's life due to competition from other species, predators etc. rather than dying from old age.

4.1.3.2. Progression through activities

To begin the session, the participants were given a picture of a common garden frog and asked to label any characteristics that made the frog well adapted to its habitat. They were told they could include behavioural adaptations or characteristics that they couldn't see. All the groups gave at least one suggestion in the feedback discussion and an example of a group's work can be seen in Figure 4.5.



Figure 4.5: Example of a group's labelling of a frog with characteristics

The next activity was completed in stages with discussions in-between. Firstly the participants were given a picture of an aquatic habitat where frogs live and a set of paper frogs that varied in their colour and markings and asked to select 10-15 frogs that they thought would live there. The groups were asked to justify their choices and all the groups made reference to camouflage and the frogs being adapted to their habitat. Next they were given a picture of a second habitat where the vegetation was lighter in colour and told that it was near to the first habitat and some of the frogs had gone to live there as the food availability was better.

In the discussion they were asked which of their frogs would survive for longer in the second habitat and most said the lighter coloured frogs. The consequences were then discussed; the longer you survive the greater the reproductive potential is. Most of the participants found it a difficult process to understand and a model was developed to help them. A simplified example, seen in Figure 4.6 was used and the steps in the process were given as:

- Variation in the population
- Some will have a characteristic that allows them to survive longer
- They will reproduce more
- The next generation will have a greater frequency of the characteristic

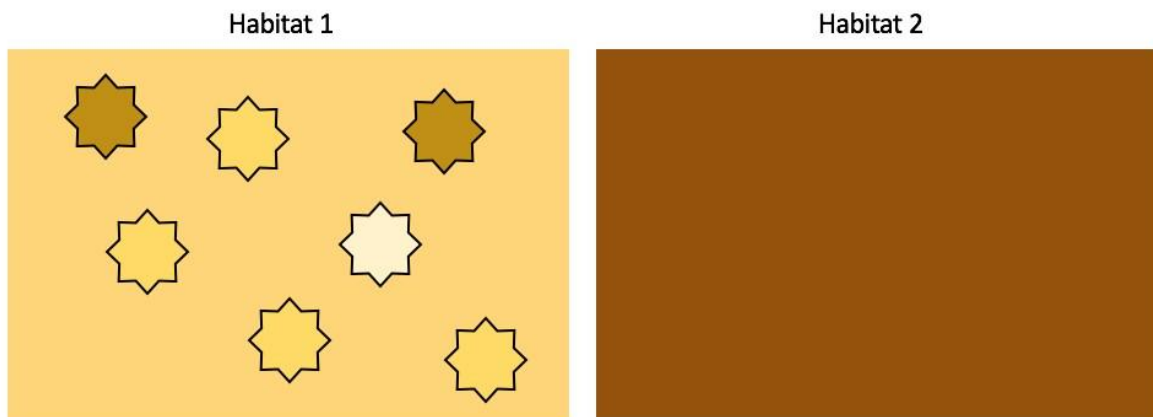


Figure 4.6: A diagram used to scaffold the stage of adaptation

The participants were asked to select 10-15 frogs to represent the offspring to be born in the second habitat and then a further 10-15 that would be the next generation to be born.

Examples of the frogs selected are shown in Figure 4.7.

During the activity some of the groups needed to be reminded about variation as all the frogs they selected to live in habitat one were identical. All the groups recognised that over time the colour of the frogs would change but there was quite a difference in how drastic that change would be. It was discussed that this would also take much longer than two generations and the activity was modelling what would happen over a much longer period.

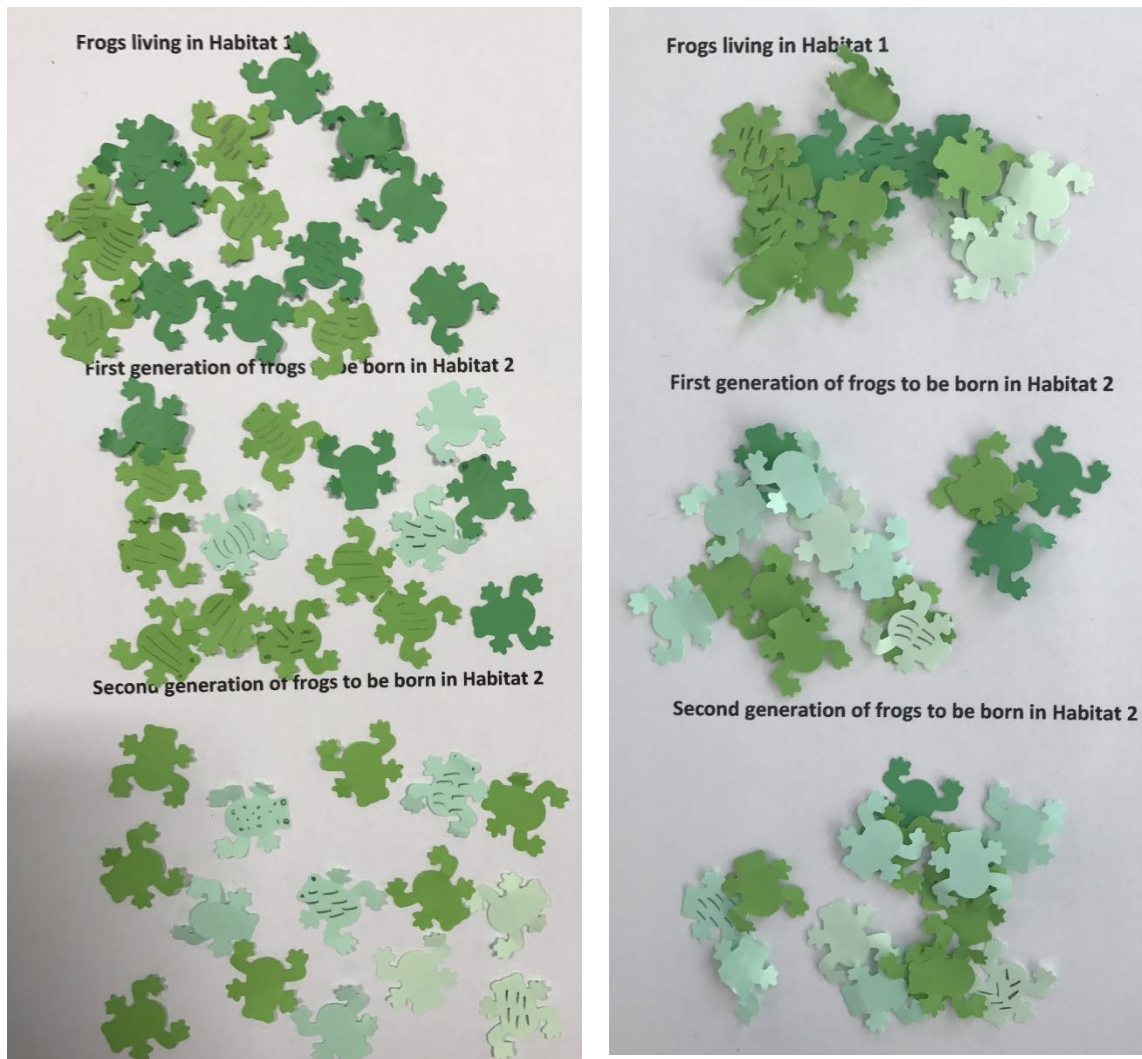


Figure 4.7: Examples of the participant's frog adaptation task

After the group discussions the participants individually wrote down an explanation and two examples can be seen in Figure 4.8. During the task some participants verbalised that they were finding it hard to write down their ideas but they were encouraged to try their best and they would have the opportunity to discuss any misunderstandings with the group afterwards.

For the groups where the light green frogs suddenly appeared (in the first example in Figure 4.7) they were asked how that happened and they referenced the inheritance lesson and how some characteristics can be hidden and then reappear. Mutations were not discussed as it was

deemed beyond the scope of the session and knowledge of DNA and genes would be required.

Explain what happened between Habitat 1 and the first generation of frogs to be born in Habitat 2.

In Habitat 1, they lived in a forest and mostly the darker frogs would survive longer and the brighter ones would die quicker because they are not camouflaged in the terrain. And in Habitat 2, the Habitat 1 offspring and they could be dark or bright because of their parents and they moved to a bright terrain and the bright frogs are going to survive longer because they live in a brighter terrain.

The frogs from Habitat 1 moved and lived in Habitat 2. ~~their~~ Their offspring would be ~~lighter~~ lighter so they camouflage into their surroundings ~~this~~ ~~that~~ this means that they would survive better in their new lighter habitat.

Figure 4.8: Written explanations given by participants

The second explanation hints at intentionality as the offspring became lighter to be better camouflaged without reference to the parents being lighter in colour. During the discussion any mention of intention was challenged by asking *can they choose to change their skin colour?*

4.1.3.3. Challenging questions

How does the skin change colour? How do the different colours suddenly appear? Could the darker colour come back again?

Box 4.5: Questions asked during the adaptation session

The challenging questions (Box 4.5) in this session were difficult to answer comprehensively because they required scientific knowledge beyond the scope of the intervention. For the colours suddenly appearing or going away they were reminded of the eye colour discussion from the inheritance session and that sometimes characteristics are hidden and can appear in later generations.

When asking if the frog's skin colour could go dark again they were encouraged to think about the environment and why it changed originally. They realised that the frogs' survival depended on their adaptation to changes in their habitat.

4.1.3.4. School context

As the example used was a frog and humans were not discussed, there were fewer contextual differences between the groups. A number of participants in both schools mentioned wildlife documentaries and how they had seen camouflaged organisms in their natural habitats.

4.1.3.5. Conceptual analysis

The participants made suggestions that involved the frogs needing to change their colour to survive which would then be inherited which implies a transformational view as the

beneficial trait is being inherited. However, the variational view of adaptation -, that it depends on differential survival and reproduction -, seemed to be well received and around half the participants referenced survival chances in their written answers.

4.1.4. Speciation session

The aim of this session was to highlight what we know about the evolutionary timeline using fossils and the tree of life to show all species have a common ancestor.

4.1.4.1. Vocabulary

Speciation was defined as the formation of new species over time. Participants were reminded about what *species* meant and how we might know that a new species has evolved.

Common ancestor was used when looking at the tree of life to define the species that two or more new species evolved from. The participants found it difficult to understand that often the common ancestor no longer exists.

4.1.4.2. Progression through activities

The session began by asking the groups to discuss how many different species currently live on Earth. Each group gave suggestions and they are shown in Box 4.6. The range of values was great and far exceeded the actual estimate of around 9 million species. The participants were asked why we only have an estimate of the number of species which led a discussion about habitats that have not been explored and the challenges of identifying new species.

100 million	5 billion
400 million	40 billion
500million	1 trillion

Box 4.6: Suggestions given by participants for the number of species on Earth

The participants were given a set of cards that had different types of organism on and asked to create an evolutionary timeline. Two examples can be seen in Figure 4.9.

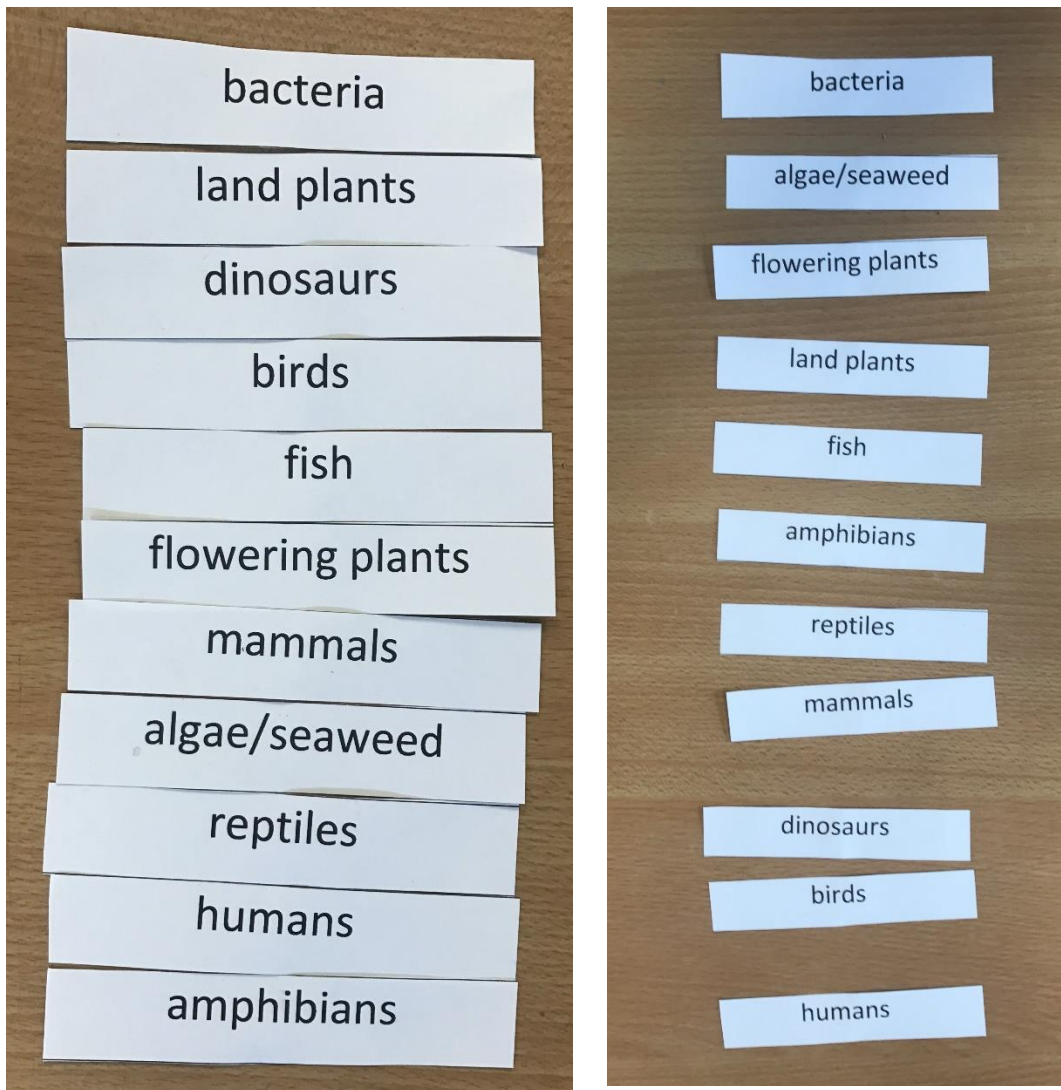


Figure 4.9: Evolutionary timeline examples

All the groups placed bacteria first and humans towards the end but the middle section caused them a challenge and generated a great deal of discussion amongst participants. They were

prompted to think about which type of organisms were similar, for example amphibians and reptiles both lay eggs. Some participants knew a lot about the evolutionary timeline as they had a natural interest and had visited museums and/or engaged with documentaries and books on the topic. Some of their questions were beyond the scope of the session and this was dealt with by suggesting they asked those questions individually and not to the whole group.

Fossils were discussed as the evidence for the timeline and the participants were told that rocks can be dated which provides an estimate of how long ago those species appeared on Earth. The discussion was moved on to how living species can be studied to determine their evolutionary relationship. A picture of five mammal limbs (Figure 4.10) was given to each group and they were asked to discuss the similarities and differences between the skeletons. Answers given by participants are shown in Box 4.7.

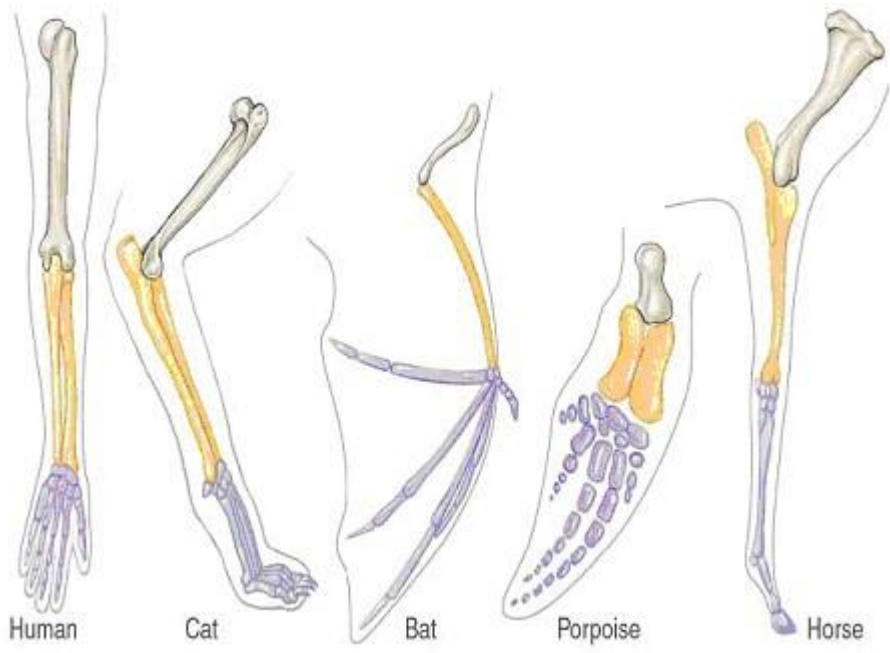


Figure 4.10: Image of mammalian skeletons given to participants

Most of the mammals have fingers
They have three sets of bones
You cannot see the bat and porpoise bones as they are covered by skin
The bat bones are longer and thinner
The horse only has one bone in its foot
The porpoise has many bones in its fingers

Box 4.7: Similarities and differences between the five mammal skeletons

Some participants used adaptation as an explanation for why the lower parts of the limbs were different. Their suggestions were used to facilitate the link between adaptation and speciation. For example, the bat having thinner bones and being able to fly allowed a discussion about the adaptation process and how this had enabled mammals to live across a wide range of habitats. From mammals the discussion was moved onto the relationship between all species and the knowledge we have about speciation.

The tree of life was introduced to participants using Figure 4.11. The interactive version from The Open University website was used in the pilot sessions but only one of the schools had access to laptops so a paper version was used with all intervention groups. The participants were told that the branching represents speciation and that a common ancestor existed at the branching point.

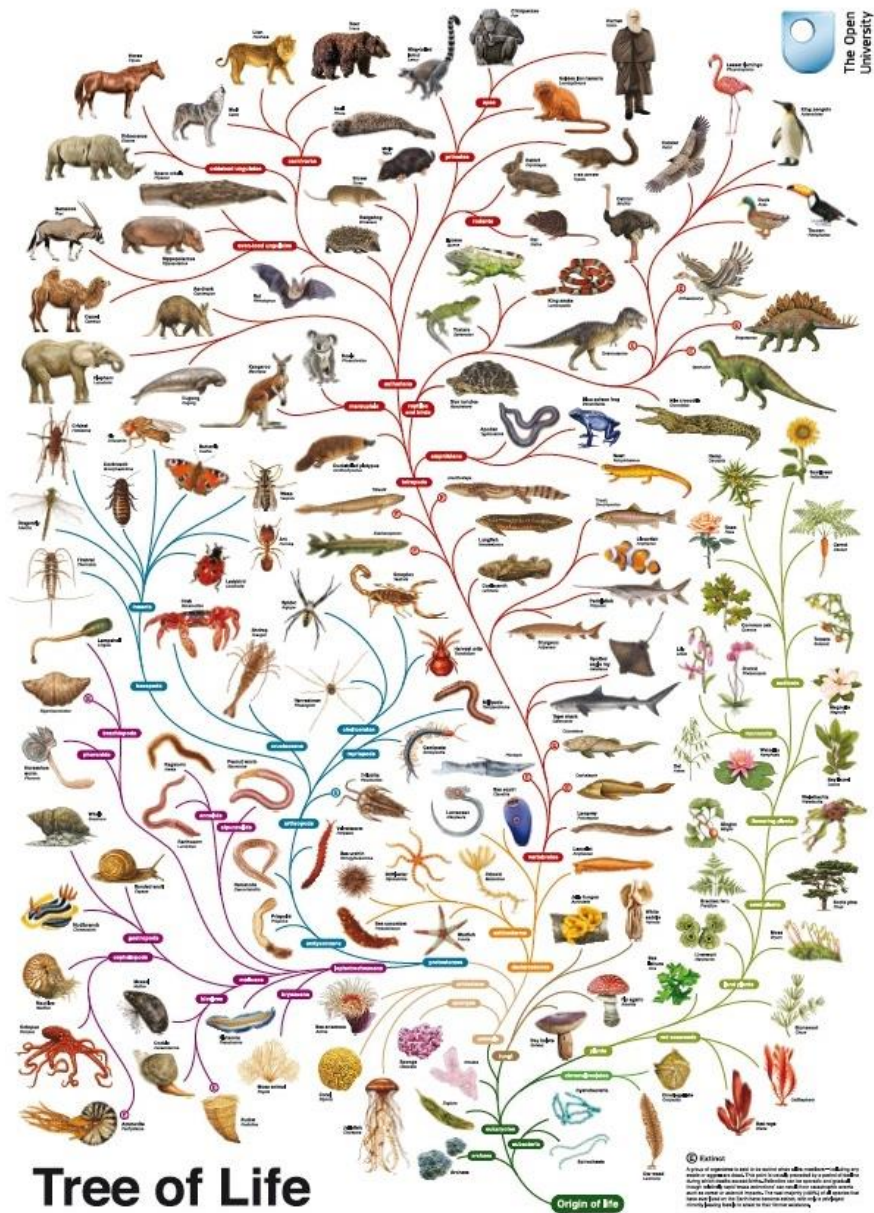


Figure 4.11: Open University Tree of Life (<http://www.open.edu/openlearn/nature-environment/natural-history/tree-life>)

The participants were instructed to explore the Tree of Life and asked what they might conclude about how closely related the species are. During the discussion the participants were asked for evidence wherever possible and guided towards describing similarities between species that shared a recent common ancestor, such as flowering plants or flying birds.

The participants enjoyed using the Tree of Life and they found it interesting to see how closely species are related to each other. They were told that there is an interactive version online that they could look at when they are at home.

The reflection section was quite challenging as many of the participants found speciation a difficult concept despite using adaptation as a basis for how organisms change over time. The long time periods involved may have contributed to their difficulty.

4.1.4.3. Challenging questions

Did dinosaurs or birds evolve first? How do we know what happened billions of years ago? Why do chimpanzees still exist if we evolved from them?
--

Box 4.8: Questions asked during the speciation session

The more in depth evolutionary questions were answered by suggesting that there are still lots of unanswered questions and scientists are always looking for more evidence. The chimpanzee type of question was answered by highlighting the role of a common ancestor, both species evolved from a species that no longer exists. The participants found these ideas quite difficult so they were referred back to the Tree of Life and reminded that the branches are where species diverged.

4.1.4.4. School context

A greater number of participants from school two had been to exposed to extra-curricular activities related to natural history. Planet Earth II, a BBC natural history series, had been on

television alongside the intervention and several participants in both schools referenced what they had seen or had questions.

4.1.4.5. *Conceptual analysis*

The tree of life showed participants that all species share a common ancestor but it was an idea that they found difficult to understand. They made references to more recent common ancestors and how closely related species were but struggled to go back further than this which demonstrated a transformational understanding.

4.1.5. Extinction session

The aim of this session was to highlight that a much greater number of species have gone extinct due to maladaptation compared to the number of species that currently exist regardless of human intervention.

4.1.5.1. *Vocabulary*

Extinction was defined within the context of a species; that there are no living individuals left. This was contrasted with *endangered* meaning when the numbers are greatly reduced but it is possible they could increase again. A few participants mentioned an organism being *extinct in the wild* but living individuals were kept in captivity.

Competition was defined as organisms competing for food, space, mates etc. Both within and between species competition was discussed.

4.1.5.2. *Progression through activities*

To begin the session, the participants were asked what they thought *extinct* meant. A summary of their suggestions is given in Box 4.9.

When something is dead
An animal you can only see in the zoo
When humans have killed all of them
When an animal has disappeared from the jungle

Box 4.9: Extinction definitions given by participants

They were then reminded that it is estimated that there are around 9 million species currently living on Earth and asked to suggest how many species have ever existed on Earth. Their answers ranged from 10 million up to billions. Whenever possible the participants were asked if they knew any examples of extinct organisms.

The discussion was moved on to the causes of extinction. Up until this point most groups had only referred to human causes. Each group was given an extinct organism and a paragraph containing information about their environment, an example is shown in Figure 4.12.

Golden Toad



The golden toad lived in rainforests in Costa Rica. They were only 5cm long and ate small insects.

The golden toad had a short breeding season – only 1 week in the rainy season. Climate change and pollution had an impact on the rainy season in the rainforest. A fungus that causes an amphibian disease increased in the warmer climate.

The golden toad went extinct in 1989.

Figure 4.12: An example of an extinct organism given to participants

The groups presented their organism to the other groups, explaining why they thought it had become extinct and answered any questions asked by the other groups. Sometimes the explanations were simplistic and repeated the provided information so they were asked questions about survival and reproductive chances to prompt them to think about adaptation. The participants were encouraged to use the scientific vocabulary they had learnt, especially competition and survival.

After the discussion the participants individually wrote down their explanations and two examples are shown in Figure 4.13.

Animal: Lesser Bilby

Describe why the animal went extinct

The lesser Bilby lived in the deserts of Australia. They lived in burrows. They went extinct in the 1950's because of an increase of wild rabbits coming into the desert. There was competition for food and burrows so the bilby died out.

Animal: Golden Toads

Describe why the animal went extinct

They lived in Costa Rica in the rainforest. They only got one week in the rainy season to breed. Which got impacted by climate change and pollution. They ate small insects and were only 5cm. There was also a fungus which had a disease that increased in the warmer climate. They ~~both~~ died in 1989.

Figure 4.13: Answers given by participants about extinct organisms

The next discussion aimed to increase awareness of the human impact on extinction. It was important for participants to recognise that extinction is a natural process and the result of organisms not being successful in their environments but human impact has increased the rate of extinction in some habitats. The participants were asked about endangered species and conservation. Their suggestions included direct methods, such as reducing deforestation and

preventing hunting and also indirect methods such as reducing energy use and recycling plastic. Their awareness of the issues was encouraging and indicated that both schools had invested time in environmental teaching.

In the reflection section many participants asked questions about their own conservation responsibilities and what they could do to help endangered species.

4.1.5.3. Challenging questions

But how do we know they are all dead? How do things come back from extinction? Will humans go extinct?
--

Box 4.10: Questions asked during the extinction session

It had been discussed in the speciation session that it is challenging for scientists to explore habitats and identify new species which led to the participants asking questions about how we can be sure that species are extinct. These questions were answered by saying that scientists use the best evidence available to them at the time but acknowledge that new discoveries are being made all the time.

The questions about specific species, including humans, could be linked back to the idea of adaptation and organisms not surviving and reproducing successfully which reinforced that the adaptation process is very important.

4.1.5.4. School context

Participants in both schools were aware of extinction and the human causes. As with the speciation lesson the participants that had a natural interest knew more about extinct organisms and the causes. School one had recently completed a project about the rainforest and many of their examples of organisms and habitat destruction were about the rainforest.

4.1.5.5. Conceptual analysis

Participants were surprised that many more species had gone extinct than existed today which is the transformational view. There was also evidence of the goal-orientated idea where species will improve towards an end goal and therefore natural extinction is unlikely. Whilst the media focus on the human influence raises awareness and encourages conservation efforts it also seems to skew understanding against maladaptation and how common extinction actually is. As a result there was very little evidence of a variational view in the sessions.

4.1.6. Domestication session

The aim of this session was to discuss the differences between domestication and adaptation in natural settings and for them to be able to describe the process of domestication using examples.

4.1.6.1. Vocabulary

Domestication was defined as humans selecting desirable characteristics in organisms and creating a population which has a greater proportion of the desirable characteristic. Many of the participants had heard of the word domesticated before and used examples of their pets.

Selective breeding or *artificial selection* is the process by which humans only allow the organisms with the desirable characteristics to reproduce for many generations.

4.1.6.2. Progression through activities

The participants were shown pictures of a small dog (Chihuahua) and a large dog (Dalmatian) and asked to discuss whether they think they are the same species. The definition of *species* was discussed to remind them. Their suggestions are given in Box 4.11.

You can mix dog breeds and they can have puppies
They look very different so I don't think they are the same species
One is much bigger than the other so I don't think they can reproduce

Box 4.11: Suggestions given by participants about dog breeds

In the discussion the participants were told that all dog breeds are the same species as they could reproduce to produce fertile offspring even though there might be some physical difficulties between breeds with very different sizes. A picture of a wolf was shown and the participants were told that all modern dog breeds have been domesticated from wild wolves. The groups were asked to discuss how they thought that might have happened. The participants initially found it hard to describe so the Chihuahua was used as an example as the size difference is the most obvious to take the participants through the stages. Separating

males and females, choosing the smallest female and smallest male and only allowing them to breed, then selecting smallest offspring and so on. The participants were also asked about behaviour, what if you wanted a good guard dog or a dog that is good with young children.

Domesticating organisms for food was discussed next using corn as the plant example and pigs for animals. They were told that this process has happened over thousands of years and still continues to ensure food availability for the growing human population. The next activity was linked by telling the participants that they were going to pretend to be cow farmers.

Pictures of four cows and four bulls with a description of their characteristics were given to the groups, examples are shown in Figure 4.14.



Alma - lots of meat, good milk production but milk sours quickly.



Boris - has lots of muscle but can cope with hot, dry conditions. Family line does not produce much milk.

Figure 4.14: Examples of a cow and bull given to participants

The participants were given one of several scenarios to discuss and were asked to select which cow and bull they would choose. Examples of scenarios and their answers are shown in Figure 4.15.

Over the next 20 years describe how you would produce a herd of cattle that produce lots of meat and creamy milk. The cattle need to be able to survive in hot climates.

I would breed Gertrude and Donald because Gertrude makes ^{lots} Creamy milk and Donald has lots of meat and comes from a line of good milk makers. After they breed and have offspring I would breed the ones closest to what I had in mind

Over the next 20 years describe how you would produce a herd of cattle that produce expensive delicious meat.

We choice Betsy and Donald. We choose Betsy because she has low milk but producted lots of tasty meat. We choose Donald as he has lots of meat, can survive well in hot climate and the family line the cattle with high quantities of milk. When they product offspring I will pick the top cow with the tasties and mast meat.

Figure 4.15: Answers given by participants in the cow domestication activity

Some of the answers only described one generation and that by breeding the cows once you would have the domesticated animal with the desired characteristics. It was discussed that it

takes many generations and many years to end up with a domesticated animal and it is an ongoing process.

Afterwards the differences between the natural adaptation process and selective breeding were discussed. Questions such as *what are the reasons for a species changing?* and *how fast does it happen?* were asked to guide the participants when comparing the two processes. If the discussion was stalling questions such as *would the domesticated animal survive in the wild?* were used to highlight that domestication is for human gain and is unlikely to promote survival in the wild.

The reflection section highlighted animal welfare issues and raised some of the challenging questions shown in Box 4.12.

4.1.6.3. Challenging questions

Does that mean my pet dog will die?

Should I not eat meat so that we don't have to domesticate animals anymore?

Is it dangerous to eat plants that aren't natural?

Box 4.12: Questions asked by participants in domestication session

Some participants were aware of the health issues caused by domesticating dogs and were concerned about their pets or what they could do to prevent the problems. This type of question could be focussed back to variation and its importance for a species survival which led participants to realise that mixing breeds of dog might be best. This was dealt with in a sensitive manner as it was important not to cause participants distress or concern about their pets.

4.1.6.4. School context

Participants in both schools were familiar with dog breeds and many had their own pets. The vegetarian participants implied they do not eat meat as they did not want animals to be bred for human gain but they had not realised that the domesticated cow had been selectively bred by humans from a wild ancestor.

4.1.6.5. Conceptual analysis

Domestication seemed to be an easier concept than adaptation as participants wrote about it more clearly which may have been because dogs and cows are more relatable and the participants have experience of them. Humans controlling the process speeds up the changes seen in species and the reasons for doing so are clearer. There was no evidence of the transformational view that the individuals are changed and most participants described the selective breeding process which is the variational view.

Some participants realised that by domesticating animals the variation has been reduced and they might be more likely to get diseases as the species would be less adaptable which demonstrated linking between the concepts.

4.1.7. Summary of intervention evaluation

The evaluation has described each session and detailed whether the sessions were implemented as planned. It also highlighted the cognitive acceleration elements of the sessions. The conceptual analysis provided evidence about the transformational or variational

views expressed by the participants. However the examples were limited and relied on field notes which did not encompass the view of every participant.

The following section will present the quantitative findings about whether the intervention improved the understanding of the evolution group when compared to the other groups.

4.2. Quantitative findings

The aim of the quantitative analyses was to ascertain if the evolution intervention had an effect on the participants' understanding of evolution as measured by the evolution assessment.

The data analysis strategy will be presented in this section. Preliminary analyses will be presented to describe the distribution of variables and whether there was equivalence at pre-test. Then the groups will be compared using ANCOVA to determine whether the intervention had an effect. Each of the concepts will then be analysed separately to explore whether differential progress was made by participants across the concepts.

4.2.1. Distribution of variables

To determine the normality of the data collected the skewness and kurtosis values were examined. The standard error and z-scores were calculated for each value to allow a p value to be determined. As seen in Table 4.1 all variables were normally distributed as the z-score values were below 1.96 indicating there were not any significant deviances from a normal distribution at $p < 0.05$.

Table 4.1: Distribution of variables for all participants

	Skewness value	Standard error	Skewness z-score	Kurtosis value	Standard error	Kurtosis z-score
Evolution assessment pre	.449	.230	1.95	.260	.457	0.57
Evolution assessment post	.040	.228	0.17	-.342	.453	-0.75
Verbal reasoning pre	-.290	.226	-1.28	.601	.449	1.34

4.2.2. Establishing equivalence at pre-test

The participants were randomly allocated to each of the groups, a procedure that is expected to lead to fewer systematic differences between groups at pre-test. However, it was necessary to test whether the groups were statistically comparable as the sample size was relatively small and differences at pre-test could be present. The pre-test data for the measures are presented below in Table 4.2.

Table 4.2: Pre-test data

	Control group (n=41)			Evolution group (n=38)			Electricity group (n=35)		
	M	SD	Range	M	SD	Range	M	SD	Range
Evolution assessment (18)	6.94	2.66	1-13	8.12	2.40	3-13	8.21	2.82	4-16
Verbal reasoning (40)	16.46	5.73	2-26	18.24	5.17	8-33	17.97	5.14	7-28

*Note - numbers in parentheses are the maximum scores.

After verifying that the data met the necessary assumptions a one-way between-groups ANOVA was carried out for each of the pre-test scores to test for any significant differences between the control and intervention groups. No significant differences were found between

the groups on any of the measures: WISC verbal reasoning test, $F(2, 111) = 1.26, p = .29$, evolution assessment, $F(2, 107) = 2.66, p = .07$. The effect sizes were all small, $d = 0.02$ (WISC verbal reasoning), 0.04 (evolution assessment). Therefore, any differences at post-test can be attributed to the intervention, as they did not exist at pre-test.

4.2.3. School and gender effects

Independent samples t-tests were conducted to evaluate the significance of gender or school differences on the evolution assessment at pre-test. There was not a significant difference between genders; $t(110) = 1.89, p = 0.07$ and 3.16% of the variance at pre-test can be attributed to gender. There was a significant difference between the two schools; $t(110) = 3.55, p = .001$. The effect size was moderate ($d = .6$) and the school accounted for 10.45% of the variance at pre-test. The random allocation to groups within schools should negate the difference between schools.

4.2.4. Comparison of groups

To establish if there are any differences between the groups at post-test an ANCOVA was employed. This allowed a covariate to be added which was suspected to have had an influence on the dependent variable, the post-test scores. The power of the F-test is increased as the within-group variance is reduced by statistically removing any unexplained variance that may be accounted for by the covariate. For the ANCOVA the WISC Similarities verbal reasoning score was added as a covariate.

It was necessary to check that the data did not violate any of the assumptions for an ANCOVA as this would compromise the results gained. ANCOVA assumes equal variances in the two groups and so the Levene's test was used and the variance was not significantly different ($p > 0.05$) for the evolution assessment. The homogeneity of intercorrelations was tested using Box's M and was also not significant ($p > 0.05$).

There are further assumptions associated with using ANCOVA. The covariate was measured prior to the intervention to ensure that the scores were not affected by the treatment condition. The reliability of the covariate must also be considered and the WISC similarities has been fully standardised and has a high value for internal consistency (.86). It also correlates significantly with the both dependent variables, science reasoning task ($r = .48$, $p < .001$) and the evolution assessment ($r = .56$, $p < .001$) and acts as a measure of verbal reasoning, therefore it can be theoretically assumed to influence scores on both cognitive and academic measures. ANCOVA assumes there is a linear relationship between the dependent variable and the covariate as well as homogeneity of regression slopes. Neither of these assumptions were violated in the data.

The evolution assessment consisted of 18 questions and each was scored as correct (one) or incorrect (zero) to give a maximum score of 18. The mean scores are shown in Table 4.3 and Figure 4.16.

Table 4.3: Mean scores on evolution assessment for the three groups

	Evolution assessment (<i>M</i> and <i>SD</i>)	
	Pre-test	Post-test
Control (n=38)	6.92 (2.69)	7.07 (2.83)
Evolution (n=37)	8.11 (2.40)	10.08 (2.79)
Electricity (n=34)	8.21 (2.81)	8.11 (2.98)

With the addition of the WISC verbal reasoning score as a covariate the difference between the groups at post-test was significant, $F(2, 105) = 5.76, p = .004, d = .6$. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for the evolution group was significantly different from the control group ($p = .001$) but not from the electricity group ($p = .25$). The effect of the verbal reasoning score as a covariate was significant, $p < 0.001$.

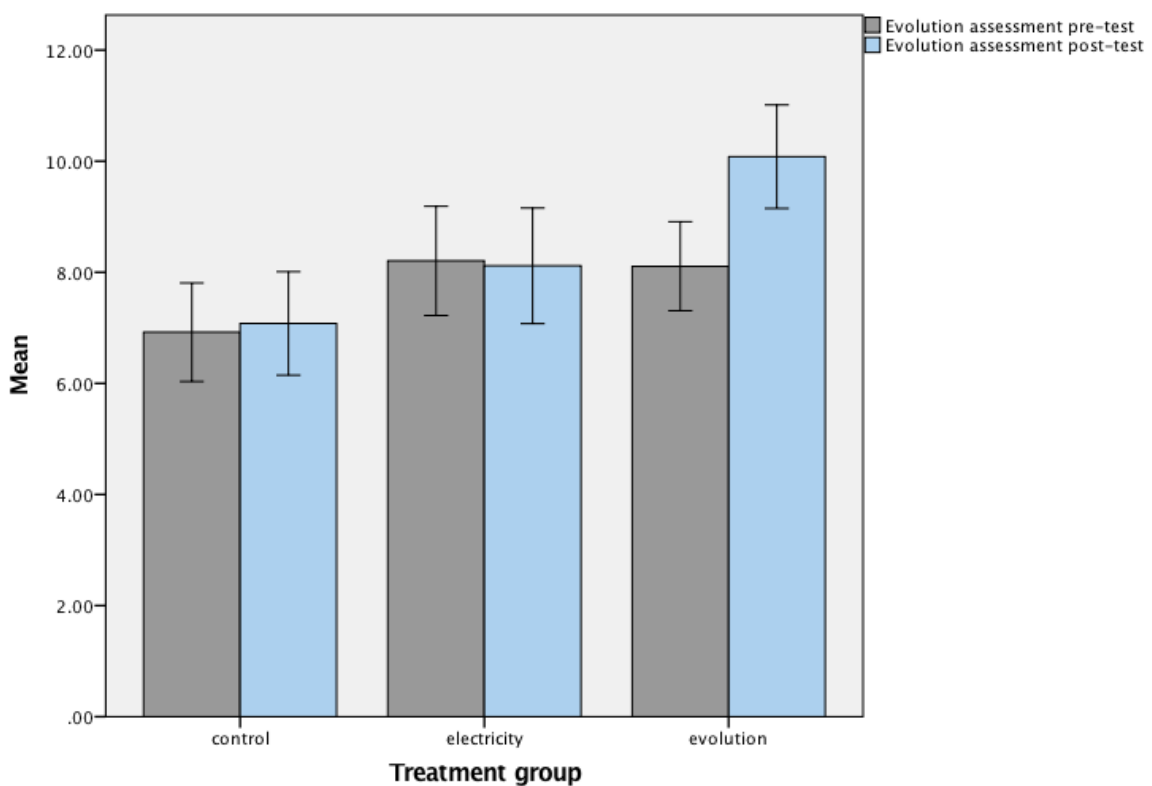


Figure 4.16: Graph to show group progress with 95% Confidence Intervals

The significant difference between groups and the medium effect size show that the evolution intervention improved the performance of the participants in the evolution assessment.

4.2.5. Evolution assessment concept scores

Each of the six concepts had three questions and a maximum score of three. Each of the concepts was analysed separately using ANCOVAs, controlling for verbal reasoning, to detect any differences at post-test however, caution must be used in the interpretation of these results as the number of items is small, which makes it difficult to detect significant differences. There were significant differences for three concepts: adaptation, domestication and speciation and the pre- and post-test scores can be seen in Table 4.4.

Table 4.4: Scores for the groups at pre-test and post-test for concepts with significant differences

	Pre-test (<i>M</i> and <i>SD</i>)	Post-test (<i>M</i> and <i>SD</i>)
<i>Adaptation</i>		
Control (n=38)	1.13 (.84)	1.02 (.91)
Evolution (n=37)	1.35 (1.03)	1.92 (.95)
Electricity (n=34)	1.32 (1.04)	1.29 (1.03)
<i>Domestication</i>		
Control (n=38)	.97 (.88)	.97 (.99)
Evolution (n=37)	1.35 (1.00)	2.27 (.90)
Electricity (n=34)	1.32 (1.06)	1.17 (.99)
<i>Speciation</i>		
Control (n=38)	1.63 (.63)	1.52 (.72)
Evolution (n=37)	1.92 (.59)	1.89 (.81)
Electricity (n=34)	2.00 (.65)	1.85 (.61)

There was a significant difference between the groups for adaptation at post-test ($p = .01$). Post hoc tests showed a significant difference between the evolution group and the control ($p = .007$) but not the evolution group and the electricity group ($p = .18$). There was a significant difference between the groups for domestication at post-test ($p < .001$). Post hoc tests showed a significant difference between the evolution group and the control ($p < .001$) and the evolution group and the electricity group ($p = .01$). The mean post-test scores decreased for all three groups for speciation and there was a significant difference between the groups at post-test ($p = .012$). Post hoc tests showed a significant difference between the evolution group and the control ($p = .031$) but not the evolution group and the electricity group ($p = .99$).

The significant difference between groups for speciation are noteworthy as they decreased. The scores at pre-test were high so that might explain why they did not improve. This could be because the participant's understanding was already strong or that the assessment questions were too easy. This can be explored further by analysing the written justifications given by participants for the speciation questions.

There was no significant difference between the groups for variation at post-test ($p = .85$), for inheritance ($p = .38$) or extinction at ($p = .78$). The scores can be seen in Table 4.5.

Table 4.5: Scores for the groups at pre-test and post-test for concepts with non-significant differences

	Pre-test (<i>M</i> and <i>SD</i>)	Post-test (<i>M</i> and <i>SD</i>)
<i>Variation</i>		
Control (n=38)	1.55 (1.01)	1.76 (1.10)
Evolution (n=37)	1.51 (.99)	1.84 (1.01)
Electricity (n=34)	1.76 (.82)	1.76 (.85)
<i>Inheritance</i>		
Control (n=38)	.79 (.74)	.84 (.82)
Evolution (n=37)	1.00 (.99)	1.16 (1.01)
Electricity (n=34)	1.06 (.98)	.82 (1.03)
<i>Extinction</i>		
Control (n=38)	.84 (.79)	.94 (.77)
Evolution (n=37)	.97 (.83)	1.00 (.74)
Electricity (n=34)	.73 (.71)	1.20 (.59)

The results from the individual concepts show that the participants in the evolution group made greater progress on some concepts than others. Further analysis of the justifications given by the participants was carried out to provide evidence about the six individual concepts and whether they can be learnt individually or whether there is an ‘all or nothing’ effect as suggested by Shtulman (2006).

4.3. Transformational or Variational reasoning

Shtulman (2006) identified his participants as exhibiting transformational or variational reasoning if they demonstrated one form of reasoning twice as many times as the other.

In the multiple-choice assessment a correct answer was deemed variational and an incorrect answer was transformational. There were 18 questions in the assessment and if the participant’s score was six or less they showed transformational reasoning twice as many

times as variational reasoning; if their score was 13 or above they showed, variational reasoning twice as many times as transformational. Using this method the participants were identified as showing transformational reasoning with a score of 6 or less, variational reasoning with a score or 13 and above. If the score was between 7 and 12 they were not classified as showing one type of reasoning.

The number of participants that could be identified as showing one type of reasoning at pre and post-test are shown in the Table 4.6 below.

Table 4.6: Number of participants that can be categorised as showing either form of reasoning

	Pre-test (% of total)	Post-test (% of total)	Percentage change
<i>All participants</i>			
Transformational	37 (32.5)	30 (26.3)	-6.2
Variational	7 (8.0)	14 (16.0)	+8.0
<i>Control</i>			
Transformational	13 (34.2)	14 (36.8)	+2.6
Variational	2 (5.4)	1 (2.6)	-2.6
<i>Electricity</i>			
Transformational	11 (32.4)	12 (35.3)	+2.9
Variational	3 (8.8)	4 (11.8)	+3.0
<i>Evolution</i>			
Transformational	13 (35.1)	4 (10.9)	-24.2
Variational	2 (5.4)	9 (24.3)	+18.9

At pre-test 32.5% of participants were identified as transformational and 8% were variational giving a total of 40.5% of the participants that showed either form of reasoning. At post-test 26.3% were transformational and 16% were variational giving a total of 42.3%. At pre and post-test just under 60% of participants did not demonstrate one form of reasoning over the other whereas Shtulman only had 11% of participants in that category. As such the % of

participants that showed mixed reasoning in the current study was too high to implement Shtulman’s scoring system. The participants in the current study were younger in age which may have affected their ability to reason one way or another.

The next step was to examine the written justifications to determine whether they could help identify participants as having either variational or transformational reasoning. Examples have been selected from both the pre and post-test to illustrate justifications that clearly demonstrate either variational or transformational reasoning.

The definitions given by Shtulman (2006) are bolded below and the examples are taken directly from the assessments.

	Variational	Transformational
Variation	Individual differences drive selection.	Individual differences are non-adaptive.
<i>Examples</i>	There are differences between the cacti that help some of them do better than others.	They are all identical to each other.
Inheritance	The heritability of a characteristic is determined by genetics.	The heritability of a characteristic depends on how beneficial it is.
<i>Examples</i>	The curlew chicks would have beaks the same as their parents as it doesn’t matter the beaks broke off.	The baby hawkfish wouldn’t need to be red to camouflage as the coral has gone.
Adaptation	Adaptation depends on differential survival and reproductive ability.	Adaptation occurs regardless of differential survival.
<i>Examples</i>	Only the ones that get the food will live long enough to have babies, the others will die too soon.	The cacti spines would grow longer when the animals try to eat them.
Speciation	All species share a common ancestor.	Only closely related species share a common ancestor.
<i>Examples</i>	All fish must have come from something that relates them all together a long time ago.	It can only be related to another tropical fish as it cannot be related to other types of fish.

Extinction	Extinction is more common than adaptation.	Adaptation is more common than extinction.
<i>Examples</i>	It takes a long time to adapt to a new environment so I think they will all die out instead.	If the environment changed than the birds would just adapt to the newer environment.
Domestication	Species can be domesticated by humans by selective breeding.	Species can be domesticated by humans by changing individuals.
<i>Examples</i>	You need to choose the smaller fish and only let them have babies as the babies will be small.	If the chicks are trained by the farmer to run faster then their babies will run faster.

There were very few clear examples and it was evident that many of the justifications did not provide enough information to say whether an explanation was transformational or variational. Both the multiple choice scores and the justification quality made it difficult to identify participants as demonstrating one type of reasoning and as such it was deemed necessary to use an alternative method to analyse the justifications.

4.3.1. Justification scoring

Wellington and Osborne (2001) developed a framework to evaluate the quality of scientific explanations and this was adapted to give a five level scoring protocol in this study, similar to the levels used by Kelemen, Emmons, Seston Schillaci and Ganea (2014).

For each question the five levels were:

- No justification given – 0 marks
- Incorrect justification given – 1 mark
- Correct description which contains some incorrect ideas – 2 marks
- Correct explanation without incorrect ideas but without the appropriate vocabulary – 3 marks
- Correct explanation with appropriate vocabulary – 4 marks

A sample of assessments completed by participants was examined to determine whether the five level scoring protocol was appropriate. For each question an expected answer at each of the five levels was written. A minimum of two examples was presented for each scoring level as guidance. This was completed for the six Hawkfish questions and trialled with several completed assessments to determine the feasibility of the protocol. The Hawkfish scoring protocol can be seen below and the full protocol for all three organisms can be found in Appendix F.

The **bold** statement is the type of answer expected and the *italicised* examples have been taken directly from the assessments or edited slightly to make the example clearer. The answers that score zero are the same for each of the six questions.

0 points : no justification given

I don't know

I guessed

It seems likely

Variation

1 point : incorrect justification given

All identical or completely different

All be completely different like fingerprints

You will not see any differences at all

These examples are not an exhaustive list, as participants' responses varied considerably.

2 points : correct description which may contain some incorrect ideas

Variation acknowledged but reasons not given

I think they would look similar but not identical

The patterns wouldn't be exactly the same

3 points : correct explanation without vocabulary

Variation acknowledged and the genetic and/or environmental causes mentioned

Every human is slightly different as their parents are different so it is the same for the fish

There would be some differences between the fish as the environment may have an impact

4 points : correct explanation with correct use of vocabulary

Variation acknowledged and the genetic and/or environmental causes mentioned using vocabulary (genes, environment, inherited)

There are differences between the fish as they will have inherited different genes from different parents

If the fish are all the same species there might be some differences due to different genes or the environment

Inheritance

1 point : incorrect justification given

Age or the environment is the only cause of their appearance

The stripes will only come when they are adults

They aren't in their right habitat so they won't have the same as their parents

These examples are not an exhaustive list, as participant' responses varied considerably.

2 points : correct description which may contain some incorrect ideas

Traits are inherited by offspring but may mention age or environment as being the cause

Babies often look similar to their parents

They will get half the stripes from their parents but not all of them as they are in a different habitat

3 points : correct explanation without vocabulary

They will still have their parent's genetic information and any adaptive changes will not be seen in one generation

It doesn't matter if there isn't coral as the fish are the same colour as their parents

Over the years the fish have had red stripes so it won't change suddenly

4 points : correct explanation with correct use of vocabulary

They will still have their parent's genetic information and any adaptive changes will not be seen in one generation using vocabulary (generation, genes, environment)

It takes many generations for an animal to completely change its markings by adapting to the environment

They will get their parent's genes but this will change over generations if they stay in the same environment

Adaptation

1 point : incorrect justification given

Changes are attributed only to the environment

They rely on the coral to keep them alive

Something in their diet makes them red

These examples are not an exhaustive list, as participants' responses varied considerably.

2 points : correct description which may contain some incorrect ideas

Mentioned surviving longer (or shorter) or having more babies but did not link them together

All the fish without stripes will die

They lived for longer and had more babies like them

3 points : correct explanation without vocabulary

Survive for longer and reproduce more, offspring will inherit the beneficial trait

They cannot control their colour but the stripes will be passed on if they survive longer

The baby fish will have more stripes if their parents were better camouflaged

4 points : correct explanation with correct use of vocabulary

Survive for longer and reproduce more, offspring will inherit the beneficial trait using vocabulary (offspring, reproduce, inherited)

If they survived for longer they could produce more offspring and the offspring would inherit the stripes from their parents

The fish that had some stripes would have had more offspring which inherited the stripes

Speciation

1 point : incorrect justification given

Species are only related to similar species or that many species evolved into a hawkfish

All the ancestors evolved into hawkfish

Maybe a goldfish turned into a hawkfish

These examples are not an exhaustive list, as participants' responses varied considerably.

2 points : correct description which may contain some incorrect ideas

Not recognising that a common ancestor exists and only describing closely related species as similar

They live around other tropical fish so they will be related

The distances in the sea are too big for them to be related to species they don't live near

3 points : correct explanation without vocabulary

The hawkfish has evolved from the same ancestor as other species as the fish adapted to their different environments.

Over time the ancestor will have developed into new fish in different environments

Different fish have come from one type of fish that lived a long time ago

4 points : correct explanation with correct use of vocabulary

The hawkfish has evolved from the same ancestor as other species as the fish adapted to their different environments using vocabulary (common ancestor, species, adapted)

Some fish will have adapted to the open ocean and some to coral reefs so they will end up different species

All fish species will share a common ancestor that all the fish species alive have evolved from

Domestication

1 point : incorrect justification given

Size being caused purely by the environment or just changing without human intervention

You need food to grow so they will be smaller if they eat less

They will just have smaller babies naturally

These examples are not an exhaustive list, as participants' responses varied considerably.

2 points : correct description which may contain some incorrect ideas

Smaller offspring are produced without clearly describing the role of humans

Then the babies will be twice as small

The offspring will be smaller if the parents are smaller

3 points : correct explanation without vocabulary

Trait being inherited and mention of human intervention (let them breed, then they breed) without vocabulary

If smaller fish are allowed to breed together you're more likely to get smaller fish

Over time they will change if you only breed specific ones

4 points : correct explanation with correct use of vocabulary

Trait being inherited and mention of human intervention (let them breed, then they breed) with vocabulary (inherited, offspring)

The offspring would inherit some of the size from their parents and over generations only letting the smallest breed would reduce the size

The size is inherited and then the pet shop can breed the two smallest offspring and so on

Extinction

1 point : incorrect justification given

Extinctions happening naturally are rare and mainly caused by humans

Humans cause extinctions

Animals will adapt before they go extinct

These examples are not an exhaustive list, as participants' responses varied considerably.

2 points : correct description which may contain some incorrect ideas

An example of a natural cause of extinction described

Lots of animals go extinct from diseases

Another fish ate all the hawkfish food

3 points : correct explanation without vocabulary

Species go extinct naturally when the population decreases without human intervention and it is more likely than adaptation

One fish gets the disease and then spreads the disease to other fish reducing the numbers

The fish die and cannot reproduce enough

4 points : correct explanation with correct use of vocabulary

Species go extinct naturally when the population decreases without human intervention and it is more likely than adaptation using vocabulary (adapt, reproduce, population)

A disease reduced the number of hawkfish so there were not enough individuals left to reproduce

The species did not have enough time to adapt to the new predators/disease so they went extinct

4.3.1.1. Second marker training

The scoring protocol was designed to be used by a non-subject specialist but it was necessary to employ a second marker to avoid bias in the scoring. It was necessary to provide the second marker with information about the biological understanding of the expected answers. Each of the 18 questions was discussed and the second marker had the opportunity to ask questions or ask for clarification at any time.

The first and second marker scored the same five randomly selected assessments. The scores were compared and any differences between scores discussed. The main source of discrepancy was between the assignment of one or two points as without strong biological understanding it was difficult at times to determine whether the justification was a complete misconception or partially correct. The incorrect answers varied considerably making them difficult to identify.

A further 10 assessments were scored independently and then compared. The level of agreement was over 90%, therefore the second marker commenced scoring a larger sample. In total the second marker scored 60 (53%) pre-test and 60 (53%) post-test assessments. The assessments were randomly assigned to include assessments from all three groups. The assessments had been anonymised and the markers were blind to the testing point and group allocation. A total of 2160 questions were marked by both markers and 1878 were in agreement (87%). Any individual score that differed by 2 points was discussed between the markers until an agreement was reached to bring them within a 1 point difference. There were no questions that differed by 3 points or more. All assessments were scored according to the protocol, with each participant receiving a score out of 72 at pre-test and post-test.

Preliminary analyses were used to describe the distribution of variables and whether there was equivalence at pre-test. Then the groups will be compared using ANCOVA to determine whether the intervention had an effect on the quality of justifications at post-test.

Table 4.7: The justification scores for each group at pre-test

	Control group (n=41)			Evolution group (n=38)			Electricity group (n=35)		
	M	SD	Range	M	SD	Range	M	SD	Range
Justification score (72)*	21.26	5.26	11-32	22.29	4.36	7-32	22.28	6.46	7-39

*Note – number is maximum score.

A one-way between-groups ANOVA was conducted for the justification scores at pre-test to test for any significant differences between the groups. There were no significant differences between the groups for the justification score, $F(2, 108) = .46, p = .63$. and the effect size was small, $d = 0.2$.

4.3.1.2. School and gender

Independent samples t-tests were conducted to evaluate the significance of gender or school differences on the justification scores at pre and post-test. At pre-test there was not a significant difference between genders; $t(110) = 1.55, p = .12$ and 2.17% of the variance could be attributed to gender but at post-test the difference had become significant; $t(110) = 2.09, p = .04$. The effect size was small ($d = .4$) and gender accounted for 3.89% of the variance at post-test with girls scoring higher.

There was a significant difference between the two schools at pre-test; $t(110) = 3.00, p = .003$, with a moderate effect size ($d = .6$) accounting for 7.63% of the variance. The difference remained significant at post-test; $t(110) = 2.54, p = .01$, the effect size had reduced to $d = .5$ and the school accounted for 5.64% of the variance.

4.3.1.3. Comparison of groups

To establish if there are any differences between the groups at post-test an ANCOVA was employed with the WISC verbal reasoning as the covariate. The assessment consisted of 18 questions and each justification had a possible score of four, to give a maximum score of 72. The adjusted mean scores, controlling for verbal reasoning, are shown in Table 4.8 and Figure 4.17.

Table 4.8: The justification scores for each group at pre and post-test

	Justification score (<i>M</i> and <i>SD</i>)	
	Pre-test	Post-test
Control (n=38)	21.25 (5.26)	21.33 (5.22)
Evolution (n=37)	22.30 (4.36)	29.13 (5.89)
Electricity (n=35)	22.28 (6.46)	22.31 (6.56)

The difference between the groups at post-test was significant, $F(2, 106) = 7.08, p = .001, d = .8$. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for the evolution group was significantly different from the control group ($p = .001$) and the electricity group ($p = .01$). The electricity and control group did not differ significantly from each other ($p = .69$). The effect of the verbal reasoning score as a covariate was significant, $p = <.001$.

For the evolution group there was a decrease in the frequency of answers that did not provide a justification (I don't know, I guessed, it seems likely or I am not sure) from 4.5% at pre-test to 2.3% at post-test.

The significant difference between groups and the large effect size show that the evolution intervention improved the quality of the justifications given by participants.

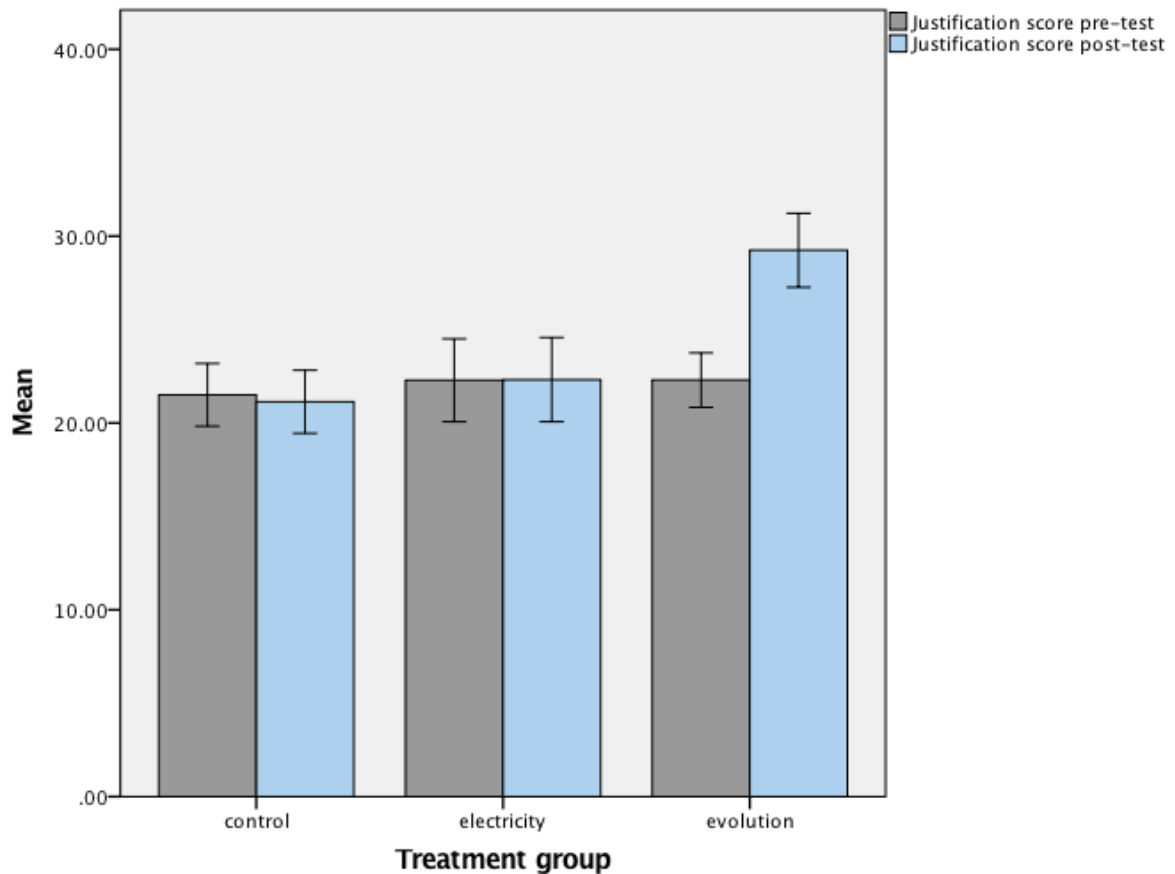


Figure 4.17: Graph with 95% Confidence Intervals

All participants in the evolution group increased their score by at least 1 (range between 1 and 30, mean 6.95). At pre-test no justifications scored a 4 but at post-test five participants scored a 4 within the assessment showing their vocabulary had improved.

4.3.2. Technical vocabulary

Technical vocabulary was introduced throughout the intervention and frequency of the words, as described in the intervention evaluation, used was counted at pre and post-test.

Words were only counted if they were used in the correct context. The frequencies can be seen in Table 4.9 below.

Table 4.9: Frequency of technical words used by each group at pre and post-test

	Frequency of technical words used correctly					
	Control (n=41)		Electricity (n=35)		Evolution (n=38)	
	Pre	Post	Pre	Post	Pre	Post
Variation	0	0	0	0	0	0
Species	10	4	12	13	12	32
Organism	0	0	0	0	0	0
Genes/DNA	10	23	15	24	21	66
Inheritance	0	1	0	0	0	20
Reproduction	0	0	0	0	1	4
Offspring	0	0	0	1	1	25
Habitat	2	2	3	4	4	8
Adaptation	18	23	11	10	16	34
Survival	5	11	8	12	17	21
Speciation	0	0	0	0	0	0
Common ancestor	0	0	0	0	0	0
Extinction	8	7	5	5	8	9
Competition	0	0	0	0	1	2
Domestication	0	0	0	0	0	0
Selective breeding	0	0	0	0	0	0
Evolve	11	22	12	15	11	11
Total	64	93	66	84	92	232

The frequency of technical vocabulary increased for all the groups: by 45% for the control group, 27% for the electricity group and 152% for the evolution group. There were differential changes for the words. Variation, organism, speciation, common ancestor, domestication, selective breeding were not used by any participants at pre or post-test. Genes/DNA increased across all the groups and offspring was the word that increased the

most. At pre-test 10 out of 38 (26.3%) of participants used the word ‘species’ at least once whereas at post-test this had increased to 18 out of 38 (47.4%). At pre-test 1 out of 38 (2.6%) of participants used the word ‘offspring’ at least once whereas at post-test this had increased to 8 out of 38 (21.1%).

At post-test, the evolution group used 2.5 times as many technical words in the justifications, compared to 1.27 in the electricity group and 1.45 in the control group. Whilst this does not provide evidence for whether the participants have a variational or transformational view it does show that the intervention has exposed them to new technical vocabulary and they have used it correctly at post-test.

4.4. Summary of key findings

The aim of this chapter was to address the first hypothesis by evaluating the effectiveness of evolution intervention. There were three different analyses that contributed to examining whether the participants moved from transformational to variational reasoning.

The evolution sessions were implemented as planned and the participants engaged with the activities throughout. Effort was made to keep the intervention sessions similar for the four groups. However the differing experiences of the participants led to participants asking different questions in the majority of the sessions, which inevitably resulted in different discussions. Their questions would be addressed within the context of the lesson and focussed back to the concept being taught whenever possible, but inevitably there was disparity between groups as they were leading the discussions and therefore the content and depth was different.

The participants who were exposed to the intervention made significant progress when compared to the other groups. Each of the six evolutionary concepts was analysed separately but the maximum score was three so it was hard to detect any changes and only two concepts (adaptation and domestication) showed significant progress for the evolution group. The CASE style of intervention is designed to promote general cognitive development but the significant progress made by the evolution intervention group indicates that explicit teaching of the concepts is required as progress was not made by the electricity group who also received the CASE style of teaching.

It was evident from both the intervention sessions and the empirical findings that some concepts were more difficult than others. Domestication seemed to be easier to understand whereas speciation proved difficult. For speciation all groups degraded which indicates the intervention did not cause the decline.

From the multiple-choice data alone the participants could not be categorised as transformational or variational and so the quality of their written justifications and vocabulary was analysed. The analyses demonstrated that their understanding of evolution improved but the detail given by participants was not enough for them to be identified as transformational or variational.

Overall the understanding of the participants was improved by the intervention but the assessment did not provide enough information to determine whether there was conceptual change from transformational to variational reasoning for each individual participant.

Chapter 5: Findings from the CASE intervention

This chapter addresses the second hypothesis by evaluating the findings from the science reasoning assessment.

The second hypothesis is that, due to the nature of the teaching programme, which is based on the use of cognitive conflict, discussion and reconstruction of the participants' solutions to problems, there will also be a measurable effect on the participants' cognitive development.

This hypothesis was addressed in two ways, the first section provides an evaluation of the intervention with regards to the CASE principles. Qualitative comments are made about the fidelity and practical effectiveness of the intervention.

The second section details the empirical findings and the aim of the quantitative analysis was to determine whether the evolution intervention had an effective on the participants' cognitive development as measured by the science reasoning task using verbal reasoning as a covariate.

5.1. Evaluation of CASE intervention

The content and delivery of the intervention was evaluated in section 4.1 and focused on the evolution content. The following section describes the intervention with regards to the adherence to the five CASE principles.

5.1.1. Concrete preparation

The concrete preparation element of each session was used to define the ideas and vocabulary that the participants should already be familiar with or may need introducing to. Within all six intervention sessions the concrete preparation element was designed using the National Curriculum to guide which topics should have been covered in previous school years and were deemed relevant for the session.

During the pilot sessions it was apparent that the knowledge which needed re-affirming or introducing varied greatly between groups of participants so the concrete preparation sections were quite explicit. During the main study, in practice some participants had very little knowledge, if any, so the concrete preparation sections had to introduce any vocabulary that would be used throughout the session. The words were defined assuming very little prior knowledge and as such the sections were similar across all groups and the fidelity was maintained.

5.1.2. Cognitive conflict and social construction

These sections required the participants to be challenged about their existing understanding and relied on the participants contributing to discussions and engaging with questions asked. As the participants were guiding much of the discussion, the quality of conversations was dependent on the other participants in the group. As a result varying levels of support were needed to ensure the sections were fruitful.

Initially some participants were reluctant to commit to their ideas by writing them down before they knew they were correct. They shared concerns about being wrong which may have hindered the cognitive conflict element of the session but this improved as sessions continued.

All discussions were based on their own experiences and were useful even if the content of each was quite different. The atmosphere in most groups was positive and the participants supported each other which was a crucial element of the social construction process.

5.1.3. Metacognition

During the first intervention session many of the participants found reflecting on their own thinking a challenge and their answers were quite simplistic. They were prompted using more specific questions to scaffold their answers. Their willingness to fully engage with this varied by group and it seemed difficult for many of them to understand what they were being asked to do.

During the subsequent sessions their ability to facilitate this themselves improved and they needed less direction. This was evident when participants referred to how they had solved a similar problem in a previous session but that said more time would be needed to fully embed

5.1.4. Bridging

The updated *Lets Think Science* resources do not have an explicit bridging section so this was also not built into the intervention design. But when possible other contexts were mentioned but due to the long time frames involved in most evolutionary concepts it was challenging.

For domestication this was easier as many of the participants had pets or were familiar with farm animals.

In summary the CASE principles were adhered to whenever possible but the nature of the sessions meant there was quite a lot of variability between the discussions held by the smaller groups within each of the four larger intervention groups.

5.2. Quantitative findings

The aim of the quantitative analyses was to ascertain if the evolution intervention had an effect on the participants' cognitive development as measured by the science reasoning task using verbal reasoning as a covariate.

The data analysis strategy will be presented in this section. Preliminary analyses will be presented to describe the distribution of variables and whether there was equivalence at pre-test. Then the groups will be compared using ANCOVA to determine whether the intervention had an effect.

5.2.1. Distribution of variables

To determine the normality of the data collected the skewness and kurtosis values were examined. The standard error and z-scores were calculated for each value to allow a p value to be determined. As seen in Table 5.1 all variables were normally distributed as the z-score values were below 1.96 indicating there were not any significant deviances from a normal distribution at $p < 0.05$.

Table 5.1: Distribution of variables for all participants

	Skewness value	Standard error	Skewness z-score	Kurtosis value	Standard error	Kurtosis z-score
Science reasoning pre	.253	.229	1.10	-.142	.455	-0.31
Science reasoning post	.007	.228	0.03	-.554	.453	-1.22

5.2.2. Establishing equivalence at pre-test

The participants were randomly allocated to each of the groups which should eliminate any differences between the groups but it was necessary to test whether the groups were statistically comparable as the sample size was relatively small and differences at pre-test could be present. The pre-test data for the measure are presented below in Table 5.2.

Table 5.2: Pre-test data for all three groups

	Control group (n=41)			Evolution group (n=38)			Electricity group (n=35)		
	M	SD	Range	M	SD	Range	M	SD	Range
Science reasoning task (6)*	2.70	1.04	1-6	2.76	1.02	1-5	3.06	1.06	1-5

*Note - numbers in parentheses are the maximum scores.

After verifying that the data met the necessary assumptions a one-way between-groups ANOVA was carried out for the pre-test scores to test for any significant differences between the control and intervention groups. No significant differences were found between the groups on the science reasoning task: $F(2, 108) = 1.20, p = .31$. The effect size was small, $d = 0.02$ (science reasoning). Therefore, any differences at post-test can be attributed to the intervention, as they did not exist at pre-test.

5.2.3. Comparison of groups

An ANCOVA was employed to ascertain if there any differences between the groups at post-test. The WISC verbal reasoning was added as a covariate as it was suspected to have had an influence on the dependent variable, the post-test scores. The power of the F-test is increased as the within-group variance is reduced by statistically removing any unexplained variance that may be accounted for by the covariate.

It was necessary to check that the data did not violate any of the assumptions for an ANCOVA as this would compromise the results gained. ANCOVA assumes equal variances in the two groups and so the Levene's test was used and the variance was not significantly different ($p > 0.05$) for the science reasoning task. The homogeneity of intercorrelations was tested using Box's M and was also not significant ($p > 0.05$).

As already discussed in section 4.2.4 there are further assumptions associated with using a covariate; neither of which were violated for the WISC Verbal Reasoning.

The science reasoning task was measured on a scale of 0-6. The mean scores are shown in Table 5.3 and Figure 5.1.

Table 5.3: Mean scores on science reasoning task for the three groups

	Science reasoning task (<i>M</i> and <i>SD</i>)	
	Pre-test	Post-test
Control	2.71 (1.05)	2.87 (1.13)
Evolution	2.78 (1.03)	3.13 (1.22)
Electricity	3.06 (1.05)	3.36 (1.32)

With the addition of the WISC verbal reasoning score as a covariate the difference between the groups at post-test was not significant, $F(2, 105) = 1.08, p = .342$ suggesting the intervention did not have an impact on cognitive development.

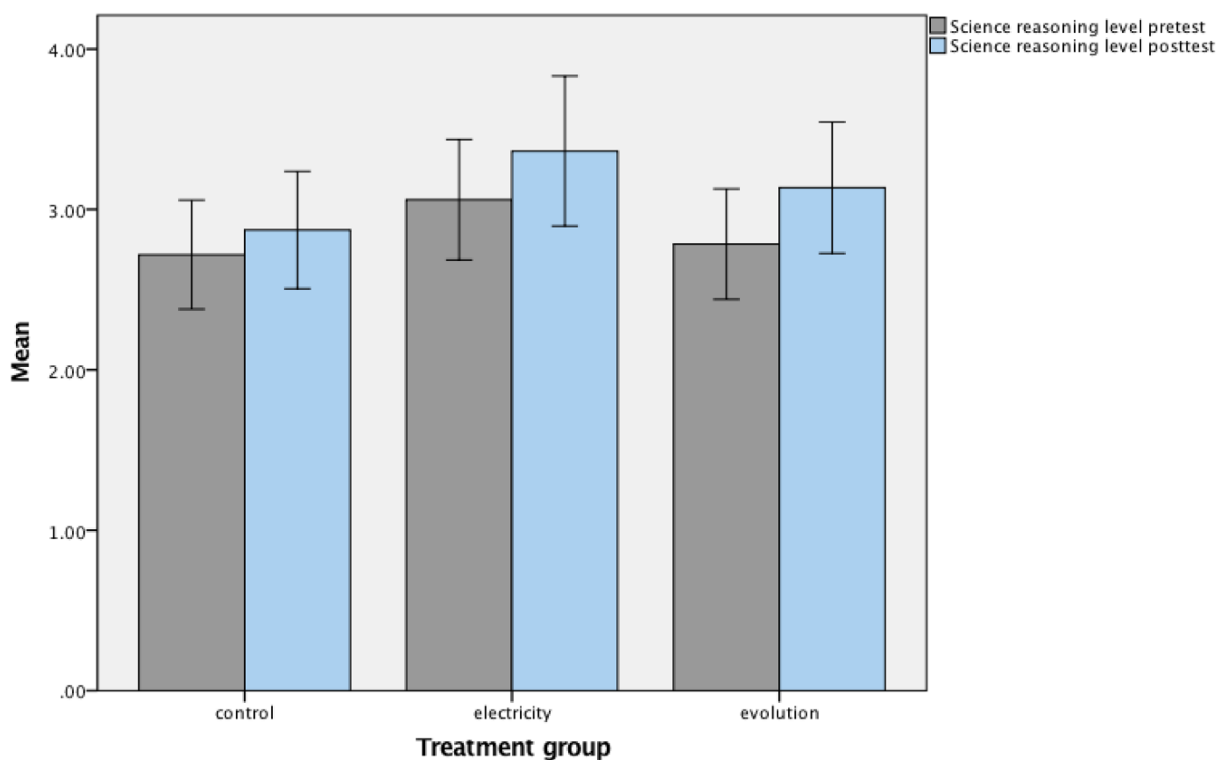


Figure 5.1: Graph to show group progress of groups with 95% Confidence Intervals

However as seen in section 4.2.5 the scores for the electricity group were not significantly different from the evolution group. Both the evolution and electricity groups made progress whereas the control group did not. As both interventions were delivered in the CASE style

this could account for the differences in the concept scores. This indicates that whilst there was not a significant difference as measured by the science reasoning task, the participants' thinking skills may have developed which allowed them to better reason in the post-test evolution assessment.

5.3. Summary of key findings

The aim of this chapter was to address the second hypothesis by evaluating the effectiveness of the CASE style of the intervention.

During the intervention the CASE principles were imbedded in each session and guided the delivery of the evolution content. The concrete preparation and metacognition sections were similar across all four intervention groups as they were structured. The cognitive conflict and social construction sections were more variable as they were guided by the discussions amongst the participants. All intervention sessions built on the participants' development of the skills needed and facilitating the CASE principles was easier during the later sessions as they knew what to expect.

The empirical results showed that the cognitive development of participants did not significantly improve when compared to the other groups. The intervention length was short compared to previous studies that gained significant results when using CASE based sessions. The newer *Lets Think Science* resources are subject specific, and the number of lessons varies per topic. If all science topics were taught in the CASE style the cumulative number would reach the number delivered in the original successful intervention (Adey and Shayer, 1990).

Overall the cognitive level of the participants was not improved by the intervention but the active control group made progress on some evolutionary concepts as described in section 4.2.5 suggesting that their reasoning skills may have improved as a result of the CASE style electricity intervention.

Chapter 6: Discussion and conclusion

The study aimed to describe the understanding of evolution using an instrument designed for the study and to examine whether a teaching intervention could improve childrens' understanding of evolution and their cognitive development. The study utilised an experimental research design where 114 participants were assessed at pre- and post-test using the evolution assessment, designed during the study, and a cognitive development measure. The previous two chapters presented the results from the measures and this chapter summarises the key findings and their educational implications, discusses the strengths and contribution to knowledge before describing the limitations and future directions for the research.

6.1. Key findings

6.1.1. First hypothesis

The first hypothesis states that explicitly teaching the six evolutionary concepts will result in conceptual change from a transformational to a variational view. This effect is deemed to be specific to the concept taught and not to be apparent in another scientific concept, namely electricity.

The intervention successfully improved the understanding of evolution of the participants in the evolution group when compared to the electricity and the control group. The overall score in the assessment of knowledge of evolutions improved significantly. Thus children in Year 6

are able to learn about the constituent concepts when taught by someone with both subject specialist knowledge and pedagogical content knowledge.

The intervention was delivered by a qualified science teacher who has a background in biology and was able to answer the participant's questions accurately and was experienced enough to have secure pedagogical content knowledge. This will not be the case in most primary schools and it highlights the need for primary school teachers to be provided with improved training and support. One must, therefore, be cautious about generalising the positive outcome observed in this study to other approaches to teaching about evolution or even to the use of the same lessons by teachers who might not be successful in dealing with pupils' questions in the same way.

The impact in the overall assessment of evolution is qualified by the observation that pupils made different levels of progress across concepts. For adaptation and domestication there was a significant improvement whereas for speciation there was a significant decline. Alternative explanations could account for the different levels of improvement in the measures for the specific concepts that are part of understanding evolution. One possibility is that, because knowledge of a difficult concept is not an all-or-nothing matter, pupils are more likely to make progress in measures of concepts with which they have some familiarity, such as the concepts of adaptation and domestication.

Topics that may promote an understanding of adaptation are included in the primary science curriculum at a younger age: 'most living things live in habitats to which they are suited' in Year 2 and then 'recognise that environments can change' in Year 4. So it is possible that the children had thought about adaptation before and were therefore more susceptible to the ideas

during the intervention. During the domestication intervention session the participants brought many of their own ideas about their pets or farm animals they knew were bred for human use. This familiarisation might have enabled them to understand the concept more easily and this was transferred into the domestication questions in the assessment about unknown organisms at post-test.

An alternative explanation is that, when a scientific concept requires considerable amounts of restructuring of previous notions, there can be an assimilation of the new ideas to the old ones, a process which results in a distorted understanding of the new concept. Vosniadou and Brewer (1992) have argued that this is what happens when children are taught that the earth is round but are not able to understand how this is possible: they form apparently odd ideas, such as conceiving of the earth as round with people living in the centre at the bottom of the sphere and the sky at the top.

A third possibility is that the design of the teaching sessions was responsible for these differences, and the sessions on adaptation and domestication were better designed than the session on speciation. This latter possibility is not entirely in line with the findings because the scores for speciation decreased for all three groups. Thus the groups that were not taught also showed a lowering of the scores, and this could not be explained by the impact of the intervention.

However, irrespective of the explanation, the content of the session about speciation could be reviewed. The choice to use an evolutionary tree during the session was based on previous studies that had highlighted the importance of understanding evolutionary relationships at the macroevolutionary level (Baum & Offner, 2008; Catley, 2006; Meisel, 2010), but an analysis

of biology textbooks found that the inclusion of evolutionary trees without clear explanation could reinforce misconceptions (Catley and Novick, 2008). Thus it is possible that not enough time was spent during the session considering how the evolutionary tree represented the process of speciation and the participants misunderstood what the branches represented.

The scores at pre-test for speciation were higher than for other concepts mainly in part to the majority of participants getting the question below correct:

Question 4 - tick 1 answer

Which of the following would a cactus be able to breed with to produce baby plants?

<input type="checkbox"/>	any plant
<input type="checkbox"/>	other cacti
<input type="checkbox"/>	an oak tree
<input type="checkbox"/>	grass

Figure 6.1: Speciation question about cacti from the evolution assessment

In hindsight this question is actually asking participants about the biological definition of ‘species’ rather than the process of speciation and may have been too easy, and thus may have had resulted in a higher score for speciation.

The findings provide evidence towards a transitional phase when participants are identified as showing mixed reasoning, confirming Shtulman’s findings with undergraduates (2006). In fact, the proportion of participants exhibiting mixed reasoning was much greater than in Shtulman’s original study, an average of 58.6% in this study compared to 11% in Shtulman’s. The proportion of participants showing mixed reasoning was stable at pre- and post-test and the numbers being classified as transformational or variational remained similar in the control

groups (percentage changes were all less than 3%) indicating that their understanding of evolution, whether correct or incorrect remains similar without instruction.

The number of participants in the evolution group identified as transformational decreased from 13 to 4 whilst the variational individuals increased from 2 to 9. The proportion showing mixed reasoning was 59.5% at pre-test and 64.8% at post-test which indicates a small increase of participants transitioning from transformational to variational. One possible explanation could be that the intervention length was too short to facilitate complete conceptual change. Another is that the participants' age has an impact on whether they can conceptualise the ideas needed to fully understand evolution and therefore the transitional phase is longer. The participants in the evolution group made movement towards a variational understanding.

The conceptual framework provided by Shtulman (2006) worked well in the study and demonstrated that the participants were able to make progress overall which indicates the six concepts underpin an age-appropriate foundation which could be built on at secondary school. However, assessing the concepts separately does not allow for the synoptic understanding of evolution to be evaluated. Existing instruments for older children (Beardsley, 2004) included an open-ended essay style question to investigate their wider understanding. Similar questions were used in the intervention sessions and participants wrote longer explanations to show their understanding. The analysis of those answers was beyond the scope of the current study but could be looked at in a future study or teachers could use the written answers in lessons to provide feedback and promote progress.

6.1.2. Second hypothesis

The second hypothesis is that, due to the nature of the teaching programme, which is based on the use of cognitive conflict, discussion and reconstruction of the pupils' solutions to problems, there will also be a measurable effect on the pupil's cognitive development.

The results from the science reasoning task did not show a statistically significant difference between the groups at post-test. The mean scores for all three groups increased and the improvement in scores was larger for the evolution group (0.35) and the electricity group (0.30) who were exposed to the CASE lessons compared to the unseen control group (0.16). These improvements were in the right direction but not big enough to be significant and this section will discuss the possible reasons for this finding which include the content-based approach, the age of the participants and the intervention length.

To date, the CASE research projects have evaluated non-content-based activities designed to promote cognitive development, rather than embedding the principles within the delivery of the National Curriculum statements. This study evaluated a content-based CASE intervention and whilst the understanding of evolution improved, the cognitive development of the participants did not improve significantly. The commercially available CASE resources that are content-based have been designed using the CASE principles but have not been evaluated to measure their effectiveness.

The reasoning skills promoted by CASE are termed 'Working Scientifically' within the science curriculum (National Curriculum in England, 2013) and are presented as a separate

section. Rather than embedding the skills within the topics they might be taught separately in school as ‘working scientifically’ projects which may reduce the links made by children between the evidence and theories being taught. If the science curriculum is to encourage children to become scientifically literate, even if they do not undertake any post-16 science qualifications, the concepts and reasoning skills need to be entwined and using the CASE principles to teach content is a possible approach. With greater exposure to the principles across several topics there might be a greater chance of children transferring the reasoning skills to other contexts. That said, in the evolution assessment, for the adaptation concept both the evolution and electricity group made significant progress when compared to the unseen control group. A possible explanation is that the participants in the electricity group benefited from the CASE intervention thinking skills developed which allowed them to reason better when faced with the adaptation questions in the assessment at post-test showing some transfer of skill.

However, it could also be suggested that by using the CASE style to teach content the CASE principles may not have been explicit enough within the intervention materials and as a result the participants did not have enough opportunities to practise the ideas.

The participants in this study were younger than in the original CASE project (Adey and Shayer, 1990) and older than the CASE@KS1 (Adey, Robertson and Venville, 2002).

Younger children appear more susceptible to CASE interventions as evidenced by CASE@KS1 (Adey, Robertson and Venville, 2002) as the intervention group made significant gains on the reasoning task after 29 CASE activities, each lasting 30 minutes, which was much less time compared to the original two year programme. However, the activities were all conducted with small groups of six participants which challenges the

ecological validity of teaching science this way as it is unlikely that a primary school will have the staff to teach the National Curriculum content in small groups. In this study the participants were grouped within a larger group of 10-15 students which is still smaller than the normal class size that would be taught science together.

The original CASE project (Adey and Shayer, 1990) involved lessons over a two-year period and the short intervention length, only six sessions, in this study may not have been long enough for the reasoning skills to develop. The skills required to engage with the CASE principles may take time to develop and the participants may progress more rapidly with increased exposure. For example, during the first intervention session many of the participants struggled to engage fully with some elements, especially the metacognition part, as they were unsure of what they needed to do. This confirms what Adey (1999) said about taking a metacognitive approach;- ‘This is time-consuming and quite difficult to do, and teachers and students need a lot of help and encouragement initially’ (p6). In subsequent sessions the participants needed less support and the discussions were of a more fruitful nature, so it might be that there is an accumulative effect and over time the progress made would be measurable. If the CASE style was adopted for all science teaching across Year 6 this would equate to roughly the number of sessions conducted in other CASE research projects.

6.2. Educational implications

The key findings have three major educational implications: curriculum design, evolution resources and teacher education.

6.2.1. Curriculum

As discussed in the introduction, the inclusion of evolution has varied since its conception in 1989 but was added to the Primary curriculum for the first time in 2014. The reasons for including certain topics at different points within the National Curriculum is unclear and this study showed that the six evolutionary concepts addressed were within the grasp of the Year six participants which could inform future evidence-based curriculum design at both primary and secondary school.

This study did not assess the synoptic understanding of evolution and the current statements within the National Curriculum are quite broad rather than being concept specific. Teachers might benefit from having greater structure which could be provided by the six concepts used in this study based on Shtulman (2006). Greater progress was made with some concepts than others and this could guide where the concepts appear within the National Curriculum, for example adaptation seemed easier to understand which may confirm its inclusion in earlier years of the curriculum (currently mentioned in Year 2 and 6) whereas speciation might need to be left until secondary school, given the results in this study and the literature stating the challenges when understanding evolutionary trees (Catley and Novick, 2008).

6.2.2. Resources used in the intervention

Primary school teachers lack confidence when teaching science and this is particularly apparent with abstract topics such as evolution (Ashgar, Wiles and Alters 2007; Rutledge and Warden 2000). Both schools that participated in this study had purchased commercially available resources to teach evolution as teachers had expressed concerns about how to plan

and teach lessons. These resources were consulted in the early stages of this study but were focused entirely on the National Curriculum statements and did not address the introductory concepts deemed necessary for a secure understanding of evolution.

In addition, the existing resources consulted did not provide guidance for teachers about addressing misconceptions or preparing them to answer the types of questions that children are likely to ask. The field notes collected during the intervention sessions in this study provide information about questions asked by participants and these could be written about along with suggested answers and explanations to support teachers when delivering the sessions. Detailed lesson plans would need to be written for each of the six sessions that would allow teachers to understand what the sessions should consist of.

The actual resources created for the six intervention sessions designed in this study could be used by teachers in primary schools to teach evolution. The resources used were all paper based and there would not be a significant cost nor are they time-consuming to implement as they have already been created.

6.2.3. Teacher training

Primary school teachers in England can complete a 3 year undergraduate course or a 1 year postgraduate route. Both options include modules about the science curriculum but more time is dedicated to English and mathematics and therefore it is difficult to ascertain how much time is spent improving pre-service teachers' science content knowledge vs their pedagogical knowledge. As there are many topics within the science curriculum it can probably be assumed that little time is dedicated to each area.

The current study demonstrated that children can make significant progress when taught by a qualified science teacher but results with primary teachers are unknown. However the results show that with training primary school teachers would be better equipped to deal with the misconceptions and questions asked by children. Teacher training could focus on the introductory concepts to minimise teachers propagating misconceptions with the broader evolutionary theory.

6.3. Contribution to knowledge and strengths

The study had several major strengths and this section will describe the contributions made to knowledge. At the time of writing, this is the first intervention study with 10-11 year old participants in England and the development of the assessment tool and the intervention allowed the progress of evolutionary understanding to be evaluated.

6.3.1. Research design

The study employed an experimental design which increased the confidence in the findings as the random allocation to groups, blocked by classroom, reduced the chance of bias and strengthened the results. The study implemented a conceptual framework proposed by Shtulman (2006) and adapted it for use with primary-aged children which gave the study a strong theoretical underpinning.

The analysis of the results from the assessment tool, the justifications and use of technical vocabulary provided rich data and knowledge about how children understand evolution.

6.3.2. Assessment tool

The development of a piloted evolution assessment is a major contribution made by the study as at the time of writing there aren't any other tools for 10-11 year olds evidenced in the literature. The rich data the assessment provided, from both the multiple-choice questions and the justifications given, allowed the participants' understanding at pre-test to be analysed giving an insight into their naïve understanding before instruction. The assessment tool could be used by teachers in their classrooms and the information could be used to inform teaching to maximise the progress made.

The assessment tool could be used by researchers to further investigate the understanding of evolution at primary school and adapted for children of various ages to further our understanding of how children think about evolution.

6.3.3. Intervention

The intervention was designed with a strong conceptual framework and consisted of six lessons which cover the Year 6 national Curriculum statements about evolution and beyond to ensure the fundamentals of evolution are covered. The results showed that the intervention significantly improved the understanding of participants meaning the resources and lesson plans could be used to successfully support children with their understanding of evolution.

6.4. Limitations and future directions

The limitations of the study are acknowledged in the following section and suggestions are provided for future studies which would go some way to address the limitations.

6.4.1. Measurement of understanding

The evolution assessment designed in the study was utilised to evaluate the effectiveness of the evolution intervention. During the analysis phase, limitations of the evolution assessment were identified and improvements would need to be made before it could be employed in future studies.

Firstly, there were multiple-choice answers written in a way that meant they could not be clearly identified as transformational or variational which made categorising participants' understanding difficult. Out of the four multiple choice answers, the wording could be changed to ensure one is clearly transformational, one is variational and the remaining two are transitional to ensure each question is consistent.

During the main study answers were provided which demonstrated that the wording of the questions could have been clearer. For example, in inheritance question in Figure 6.2 a couple of justifications were provided that said the beaks would be short as the chicks were young. The question could be improved by editing the final sentence to: 'Is it likely that when the curlew chicks grow up they'.

Question 3 - tick 1 or 2 answers

A male and female curlew both had long beaks but they broke off in the sand. They have 10 curlew chicks. Is it likely that the curlew chicks

<input type="checkbox"/>	will mostly have short beaks
<input type="checkbox"/>	will mostly have long beaks
<input type="checkbox"/>	will have a mixture of short and long beaks
<input type="checkbox"/>	will have longer beaks than their parents

Figure 6.2: Curlew inheritance question

When the justifications were analysed it was challenging, at times, to determine whether a participant's understanding was transformational or variational as the justifications given by the participants did not provide enough information for their understanding to be clearly assessed. Although it would be time consuming, it would be interesting to ask the participants to orally explain the reasoning behind their choices to ensure their genuine understanding, whether correct or incorrect, had been established.

The study did not employ a delayed post-test so it was not possible to determine whether the significant gains in the participants' understanding were sustained. It would be interesting to follow up with participants once they have started secondary school to explore whether their improved understanding had an impact on their understanding when exposed to new topics in science. The assessment tool measured participants' understanding of the constituent concepts that were age appropriate, the idea being that this will lead to a secure understanding of evolution later on. A future study could follow up and look at evolution as a whole, using not constituent concepts but a broader understanding of the process. There are existing assessment tools designed for older children that could be used.

6.4.2. Intervention

During the study the intervention was delivered by a trained biology teacher whereas in reality less than 3% of primary school teachers have a science background (The Royal Society, 2010). The ecological validity of the study would be improved if primary school teachers delivered the intervention within their normal classroom setting. This would require intervention training to ensure the teachers were familiar with the tasks and were introduced to the types of questions they might be asked by participants. This would allow the effectiveness of the intervention to be evaluated when given by non-specialists and would allow the intervention to be used to improve the understanding of children in any primary school setting.

Whilst the intervention length was long enough to improve participants' understanding of evolution it would be interesting to explore whether delivering other scientific topics in the CASE style over a longer time period would impact the cognitive development of participants. The original CASE intervention (Adey and Shayer, 1990) involved lessons over a two year period which led to long-lasting results on external measures including GCSE exams. If the CASE style was to be utilised for other science topics in Year 6, the number of sessions would be similar to the original CASE intervention and an impact on cognitive development might be detected.

6.5. Conclusion

Evolution is a widely misunderstood theory amongst the general population and this study has provided evidence that children at primary school can make significant progress with the six concepts that underpin a strong understanding of evolution.

Encouragingly, the participants in the study were keen to engage and always willing to partake in the discussions and activities and if they were to be ‘hooked’ on the topic there is a good chance they would continue to be interested. This is particularly pertinent at a time when there is an increasing focus on protecting the environment and climate change which are regularly featured in documentaries or on the news. Evolution can provide explanations towards why these issues are important and encourage discussions and evidence evaluation which are crucial skills to develop in young people if we are to improve the scientific literacy of the population.

That said, adequate time needs to be dedicated to science teaching at primary school which can be a challenge with external pressures being placed on success primarily in English and maths. This coupled with a lack of confidence can lead to minimal science lessons throughout the year, especially in Year 6 when children take their SATS. With structured training and the provision of high quality resources teachers could be supported to help to provide children with a good understanding of evolutionary concepts before they move on to secondary school.

In conclusion, the study has offered a novel approach to assessing the understanding of evolution of primary aged children and provided evidence to show that the concepts are

within the grasp of children of this age when taught effectively. There is great potential for continued research to evaluate the assessment tool and intervention on a larger scale before being used in schools to support teachers to provide high quality evolution education, increasing the positive outcomes more generally for science education at primary school.

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Appendix A: Evolution Assessment

Hawkfish



Hawkfish are tropical fish which live in coral reefs around the world. They have a red-striped pattern which helps them hide in the coral where they hunt for their prey.

The questions do not follow on from each other - each question is about different hawkfish.

Question 1 - tick 1 answer

On one coral reef there are 150 hawkfish and a scientist recorded their red markings. What would the scientist have seen?

all the fish would look the same

the fish would all have completely different markings

there would be some differences between the fish

the red markings might change whilst the scientists are there

Because

Question 2 - tick 1 answer

A male and female hawkfish produce many eggs. The eggs are taken from the coral reef and placed in a fish tank to hatch without any red coral. What will the baby fish look like?

<input type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>

will be completely white

will be white with as many red stripes as their parents

will have half as many red stripes as their parents

will be completely red

Because

Question 3 - tick 1 answer

How did the hawkfish develop the red-striped pattern?

<input type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>

the fish that were born with more red stripes were better camouflaged so could catch more food and lived for longer

the fish ate food that made them have red stripes and then their baby fish had red stripes

the fish that were born with better camouflage had babies that were better camouflaged

the red stripes appeared when the fish went to live in the coral

Because

Question 4 - tick 1 answer

The ancestor of the hawkfish

- could only be another tropical fish
- could only be a fish that is now extinct
- could be the same as all other fish
- could be the coral reef

Because

Question 5 - tick 1 answer

A pet shop wants to breed hawkfish to sell them for people to keep in their fish tanks. The hawkfish need to be smaller than they are in the wild. How could the pet shop produce lots of small fish from the existing wild parent fish?

- feed the baby fish less so they don't grow as big
- choose the smallest male and smallest female to breed
- keep the fish in a smaller tank and they won't grow as big
- let the fish breed naturally and they will end up smaller

Because

Question 6 - tick 1 answer

What could cause hawkfish to become extinct (they no longer exist)?

<input type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>

only if humans caught them all

if another type of fish ate the same food as the hawkfish

it is unlikely they would go extinct because they would adapt

a disease could make the hawkfish sick and many could die

Because

Cacti



Cacti (lots of cactus) are plants which are covered in spines instead of leaves. They live in hot countries and their ancestors did not have spines.

The questions do not follow on from each other - each question is about different cactus plants.

Question 1 - tick 1 answer

If you looked at many cacti in the desert would they

<input type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>

all be slightly different because they had different amounts of food

all look the same

all be slightly different because they grew like that

only look different if they were different types of cactus

Because

Question 2 - tick 1 answer

A gardener wants to produce many cacti that do not have spines so that people do not hurt themselves. What should the gardener do?

<input type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>

the gardener should cut the spines off all his cacti and then breed them together so their baby cacti do not have spines

the gardener should choose the cacti with the smallest spines to breed together

the gardener should try a different plant food that will cause the spines to fall off

the gardener should let the cacti breed normally and the spines will just get smaller

Because

Question 3 - tick 1 answer

Cacti have spines that prevent them being eaten by animals. How do you think the spines developed?

<input type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>

some cacti happened to have longer spines and lived for longer as animals did not eat them

cacti grew their spines on purpose so animals wouldn't eat them

some cacti happened to have smaller spines and did not survive as animals ate them

cacti that lived in hotter places could grow longer spines

Because

Question 4 - tick 1 answer

Which of the following would a cactus be able to breed with to produce baby plants?

<input type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>

any plant

other cacti

an oak tree

grass

Because

Question 5 - tick 1 answer

In 100 years time the cacti could be extinct (when there are no living cacti left). Why might the cactus have become extinct?

- the environment stayed the same but the cactus could no longer survive
- another plant was better at getting the food and water
- humans picked them all and didn't grow any new ones
- because the cactus adapted into a new type of cactus

Because

Question 6 - tick 1 answer

The seeds from a cactus were taken away and planted in a desert in a different country where the most common plant is grass. Which of the following are true?

- the new plants would look like grass plants so they are camouflaged
- the new plants would look like cactus plants
- you cannot tell what the new plants would look like
- the new plants could look like any other type of plant that lives there

Because

Curlew



Curlews are birds that live along the sea shore in America. They eat crabs and other shellfish and they have very long beaks which they stick into the sand to catch the crabs and shellfish.

The questions do not follow on from each other - each question is about different curlews.

Question 1 - tick 1 answer

A bird watcher is looking at a group of adult curlew birds on the sea shore and he notices their beaks are all different lengths. Why are the beaks different lengths?

some birds will have longer beaks than others as they were born that way

it will only depend on their diet and how much they eat

it will depend on how long their parents beaks were

it will only depend on how old the bird is

Because

Question 2 - tick 1 answer

A farmer wants to start breeding curlew birds. The farmer catches 20 birds and wants to produce more than 100 birds that can run faster than curlew birds already run. What should the farmer do?

- let the birds breed naturally and then train the chicks to run fast
- only let the fastest male and female curlew breed and have chicks
- let the birds breed naturally and eventually they will be able to run faster
- feed the birds special food that make them run faster so their chicks will be able to run faster

Because

Question 3 - tick 1 answer

A male and female curlew both had long beaks but they broke off in the sand. They have 10 curlew chicks. Is it likely that the curlew chicks

- will mostly have short beaks
- will mostly have long beaks
- will have a mixture of short and long beaks
- will have longer beaks than their parents

Because

Question 4 - tick 1 answer

If the curlew bird's environment changed which of the following is most likely?

- curlew birds could be the same as they are now
- curlew birds could have turned into a new type of bird
- curlew birds could have become extinct (they would no longer exist)
- humans caused the curlews to become extinct

Because

Question 5 - tick 1 answer

Why do you think curlews have longer beaks now then they did in the past?

- the curlews born with longer beaks could catch more crabs and lived for longer
- the curlews grew their beaks so they could catch more crabs
- the curlews stretched their beaks as they tried to catch more crabs
- the curlews born with shorter beaks couldn't catch enough crabs and died sooner

Because

Question 6 - tick 1 answer

Two groups of curlew birds became separated and lived in different environments. What might happen to the two groups of curlew birds?

<input type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>
<input type="checkbox"/>

eventually the two groups would no longer be able to breed with each other

each group would change and the birds would still be able to breed with each other

each group would not change

each group would adapt to their new environment

Because

Appendix B: Electricity intervention summary

Session 1

The aim of this session was to introduce what a circuit is and to introduce the concepts that would be needed in subsequent sessions.

Pillar of CA	Description
Concrete preparation	<p>Students were shown an actual light bulb and asked to discuss how they could make it light up. The children discussed their ideas in their groups and then were given the opportunity to share. Most of the answers mentioned electricity but further detail was lacking.</p> <p><i>What do I need to get this bulb to light?</i></p>
Cognitive conflict and social construction	<p>The children were asked to draw sketches to show they would need to get the bulb to light. Each group presented their sketches and described their ideas and the remaining groups could question, comment or challenge what has been said with the researcher if the discussion required guidance. If the ideas have not been mentioned they were asked questions.</p> <p><i>What is a circuit? What is needed in the circuit? Do you agree with that idea? Can you explain it another way?</i></p>

Cognitive conflict and social construction	Each group used themselves as equipment (bulb, battery, wires etc) to model a working circuit to the rest of the groups. Each group presented their ideas explaining the reasons behind what they are showing. The other groups were encouraged to question the presenting group and challenge their explanations. <i>Can you explain what role you are playing?</i>
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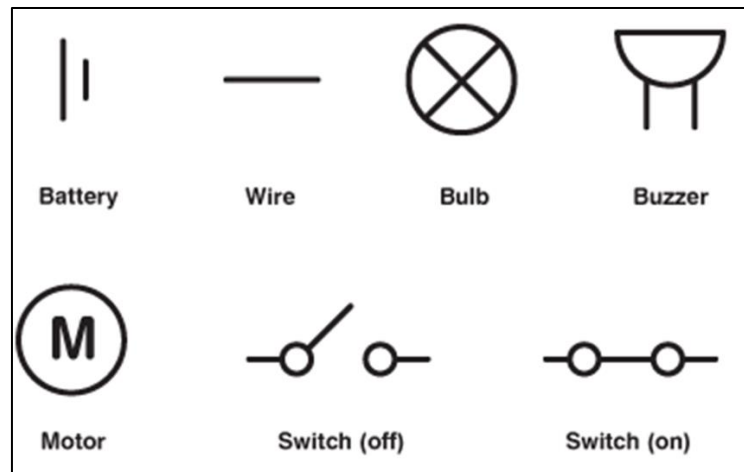
Metacognition	After the activities time was left to reflect on what they had learnt. The vocabulary learnt was recapped and discussion was promoted about what they had found difficult and which new ideas they had found useful to help them better understand. <i>What would have helped you complete the tasks more easily?</i> <i>Do you think there are any circuits in your homes? What was difficult about the task? Did anyone show you anything that helped you to better understand circuits?</i>
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Session 2

The aim of the session was to explore what makes a circuit work and that some materials are conductors and some are insulators.

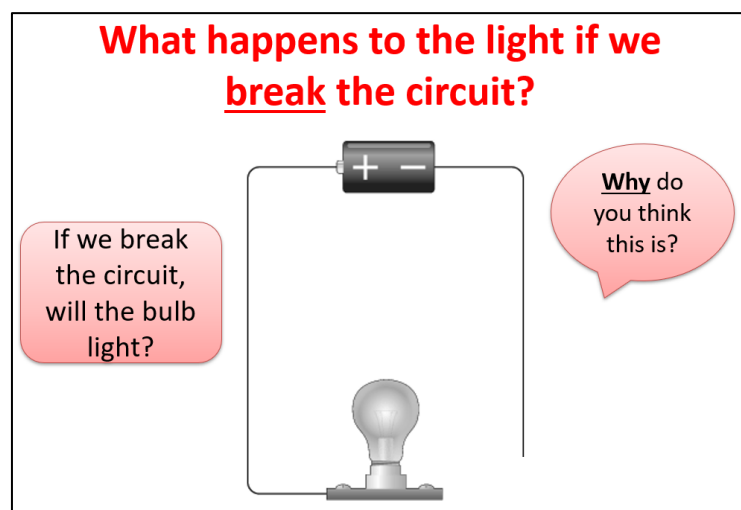
Pillar of CA	Description
Concrete preparation	The children were provided with standard circuit symbols (as seen below) and reminded what they are as these should have been taught in Year 4. However many students were

unfamiliar with the symbols so they were all defined.



Cognitive conflict and social construction

Each group was given a pack of cards with various circuit diagrams on. In their groups they were asked to classify the circuits into ones where the bulb will light and ones where it won't. After their group discussions they were asked to choose one that they were not sure about or they found most challenging and presented their ideas to the rest of the groups. Some of the examples (such as the below) were then discussed as a group.



Which circuits are you sure about and why? What is it we are not sure about? What could we change in the circuit to make the bulb light up?

Cognitive conflict and social construction

Each group was provided with a bag containing objects (metal spoon, string, penny coin, elastic band, paper clip, cotton wool and cardboard) and asked to discuss which would conduct electricity and which won't. Each group then presented their ideas with reasons and the words conductor and insulator were introduced if the children did not use them.

What do you think will happen to the bulb if we add these objects one at a time to our circuit?

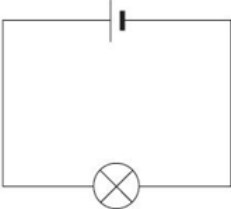
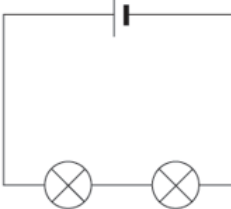
Metacognition

To finish the session the groups were asked to summarise their thinking and challenged to decide and asked what they would like to investigate further.

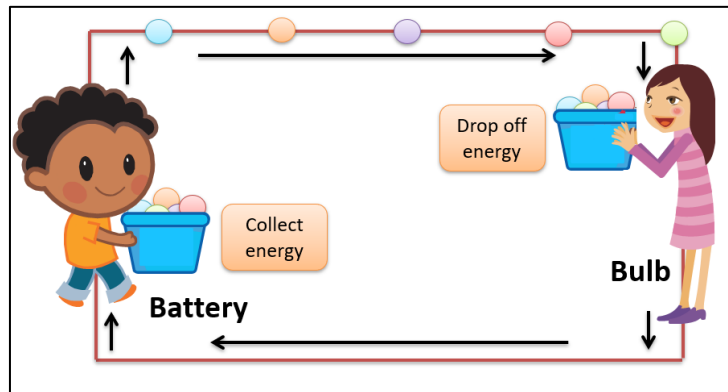
Have you changed your mind about anything today and how did that happen?

Session 3

The aim of the session was to explore what factors affect how a circuit work and what electricity actually is.

Pillar of CA	Description
Concrete preparation	<p>The students were provided with equipment to build a circuit and were asked to build a simple circuit with a bulb and explain why the bulb lights up.</p> <p><i>What is the circuit symbol for a bulb? Why does the bulb light up?</i></p>
Cognitive conflict and social construction	<p>The students were asked to discuss how they could make their bulb brighter or dimmer. After their group discussions they were asked to feedback their ideas and then they were asked to build circuits to find out if their ideas are correct. If they struggled to come up with ideas they were given the worksheet below to guide them.</p> <div data-bbox="555 1077 1297 1491" data-label="Complex-Block" style="border: 1px solid black; padding: 10px; margin: 10px 0;"> <p style="text-align: center;"><u>Let's Build!</u></p> <div style="display: flex; justify-content: space-around; align-items: flex-start;"> <div style="text-align: center;"> <p>1.</p>  </div> <div style="text-align: center;"> <p>2.</p>  </div> </div> <p>3. What happened to the bulb when you added another bulb? What would happen if you added another battery?</p> </div> <p><i>What could you change in the circuits? What is it we are not sure about? Where in your house can you change the brightness of bulbs?</i></p>
Cognitive conflict and social construction	<p>Each group was asked to write down an explanation about why the bulb is brighter when there are more batteries.</p>

Each group then presented their ideas with reasons and the diagram below was shown to aid the explanation. As a challenge they were asked to explain why the bulbs were dimmer when more were added.



Why do you think the bulbs got brighter/dimmer? Is the electricity used up?

Metacognition

After the activities time was left to reflect on what they had learnt.

Did any of the activities today make you think differently?

What was the most difficult idea to understand? In your group can you give an example of when someone else's idea was useful?

Session 4

The aim of this was to investigate the role of different components in a circuit and how these affect a bulb.

Pillar of CA	Description
Concrete preparation	<p>The children were asked to discuss what they know about making a bulb work and an idea is taken from each group and shared. The key ideas were prompted about the concepts if the children did not share them.</p> <p><i>What is a circuit? How can you make a bulb brighter? How can you turn a bulb on and off?</i></p>
Cognitive conflict and social construction	<p>The groups were given a picture of a monster's face with a hole where the nose should be. The groups were asked to discuss what materials they would need to make the nose light and to draw a sketch. Each group then shared their ideas whilst others groups were asked for suggestions that would improve their plan. Each group then created their circuit using electricity equipment demonstrating how they could turn the light on and off.</p> <p><i>Why might that not work? Would you need any equipment that you do not have? What would happen if the battery ran out?</i></p>
Cognitive conflict and social construction	<p>The groups were challenged to make the monster's face into a more exciting toy by planning their circuit and then drawing a sketch of the equipment they will need. They then</p>

constructed their game and demonstrate it to the rest of the groups.

What equipment will you need? How can you control different bulbs/buzzers etc? Could you have one bulb on and one bulb off?

Metacognition

Groups were encouraged to reflect on their learning and questioned further about improvements they could have made depending on what circuit they made. A general discussion of what went well and what challenged their ideas was facilitated.

How did you get 2 eyes to work on one circuit and could you make them flash? What did you have to think about to make this work? Did the order that you did things matter? How did you solve any problems you encountered?

CENTRAL UNIVERSITY RESEARCH ETHICS COMMITTEE (CUREC)
Form CUREC 1A Checklist for the Social Sciences and Humanities



The University of Oxford places a high value on the knowledge, expertise, and integrity of its members and their ability to conduct research to high standards of scholarship and ethics. The research ethics clearance procedures have been established to ensure that the University is meeting its obligations as a responsible institution.

They start from the presumption that all members of the University will take their responsibilities and obligations seriously and will ensure that their research on human subjects is conducted according to the established principles and good practice in their fields and in accordance, where appropriate, with legal requirements. Since the requirements of research ethics review will vary from field to field and from project to project, the University accepts that different guidelines and procedures will be appropriate.

- Please check the [CUREC flowchart](#) and [NHS flowchart](#) first to see if you need ethics approval.
- Please complete this form using a word processor and email it, together with your [supporting documents](#), to your [Departmental Research Ethics Committee \(DREC\)](#) (if applicable). If you don't have a DREC please email this form to ethics@social.ox.ac.uk using your official ox.ac.uk email address. **Only emailed applications will be accepted.**

WHAT THIS CHECKLIST IS DESIGNED FOR

This **CUREC 1A checklist** is designed largely for research that falls within the Divisions of Social Sciences and Humanities where ethical issues are relatively few and straightforward. Interviews, field work and oral history are also included in the CUREC process.

The **full CUREC 2 application** is only required where certain project characteristics (e.g. type of participants, or procedures) result in a more complex set of ethical issues. It is expected that only in a limited number of cases will it be necessary for researchers to complete a CUREC 2 application. The checklist below will direct you to a CUREC 2 application if needed.

WHAT THIS CHECKLIST WILL NOT ASSESS

This checklist does not cover research governance, satisfactory methodology, or compliance with the requirements of publishers when administering their tests or questionnaires. As principal researcher, it is your responsibility to ensure that requirements in these areas are met.

CUREC does not review studies classed as **audit** (see [Glossary](#) and [Decision Flowchart for CUREC](#) on our website).

Further information on the University's research ethics procedures are available from the CUREC website: www.admin.ox.ac.uk/curec.

Appendix C: CUREC

SECTION A: Filter for CUREC2 application	
This section determines whether your study raises more complex issues which require the completion of a full application for ethical review, known as the CUREC 2 application.	
(Please mark 'X' in the 'Yes/No' column as appropriate to indicate your response.)	
1. Are research participants classed as people whose ability to give free and informed consent is in question ? (This may include those under 18 (though see "competent youths" in FAQ C12), prisoners, or adults "at risk".) Your attention is drawn to the University's Safeguarding Code of Practice and its implications for researchers involving children or adults at risk, including the need for the work to be risk assessed and for researchers to undertake related training. (Note: If any of your participants are aged 16 or under, please answer 'Yes' here and also answer question 5 below.)	Yes <input checked="" type="checkbox"/> X No <input type="checkbox"/>
2. By taking part in the research, will participants be at serious risk of criminal prosecution (e.g. by providing information on drug abuse or child abuse)?	Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> X
3. Does the research involve the deception of participants?	Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> X
4. Does your research raise issues relevant to the Counter-Terrorism and Security Act (the Prevent duty) , which seeks to prevent people from being drawn into terrorism? Please see advice on this on our Best Practice Guidance web page .	Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> X
If you have answered 'No' to all of the questions above please go to Section B . If you have answered 'Yes' to any question above continue to question 5 below.	
5. Is your project covered by a CUREC approved procedure (formerly known as "CUREC Protocols")? If yes, please give research procedure number(s): 25	Yes <input checked="" type="checkbox"/> X No <input type="checkbox"/>
If you answered 'Yes' to ANY of questions 1-4, and answered 'No' to question 5, please stop completing this checklist and do not submit it for ethical review. Instead, please complete the CUREC 2 application form from the CUREC website. Then submit the CUREC 2 form for ethical review. If you answered 'Yes' to ANY of questions 1-3, and answered 'Yes' to question 5, please go on to Section B .	
SECTION B: Contact details and project description (NB: must be typed not handwritten)	
Contact details:	
1. Principal researcher/supervisor (title and name) (if student research):	Dr Judith Hillier and Professor Terezinha Nunes
2. Name of student (if student research):	Jennifer McGowan-Smyth
3. Degree programme, e.g. DPhil, BA, MPhil, BSc, MSc (if student research):	DPhil Education
4. Department or Institute name:	Department of Education
5. Address for correspondence (if different from 4 above):	
6. University e-mail (not private email) and telephone contact:	jennifer.mcgowan-smyth@education.ox.ac.uk
7. Name and status of others taking part in the project, e.g. third year undergraduate, postdoctoral research assistant:	

SECTION B continued	
Project description:	
8. Title of research project:	Teaching evolution at primary school
9. List of location(s) where project will be conducted:	Bristol and Oxford, UK.
10. If your research involves overseas travel or fieldwork, by the time the research starts, will you have completed and returned a travel risk assessment form? (This has to be approved by your department before you travel, if you are travelling overseas, you are strongly advised to take out University travel insurance .)	<p>Yes <input type="checkbox"/></p> <p>No <input type="checkbox"/></p> <p>N/A <input checked="" type="checkbox"/></p>
11. Anticipated duration of research project overall:	18 months or 1.5 years (maximum 5)
12. Anticipated start and end dates of the research project involving human participants:	<p>From: (01/11/16)</p> <p>To: (07/05/18)</p> <p>Please note that you will need ethics approval before you start your research. CUREC/Ae may take up to 30 days to process.</p>
13. Title and very brief and simple lay description of research (about 150 words), plus description (about 200 words) of the nature of participants.	
<p>a) Title and brief lay description of research (150 words). When describing the research, please include your methodology, how you are applying professional guidelines, and the use to which results/data will be put. Please also declare any conflicts of interest here.</p>	
<p>Teaching evolution at primary school</p> <p>This CUREC application is for the intervention phase of a DPhil project which has already received CUREC approval for the piloting of the assessment instrument (October 2015) and the piloting of the intervention lessons (June 2016).</p>	
<p>Aims</p> <p>The aim is to implement and evaluate an evolution teaching intervention using an experimental design with both an active and an unseen control group.</p>	
<p>Methodology</p> <p>The methodology has been designed with reference to protocol 25. Approximately 120 Year 6 children will be assessed at pre-test using an evolution assessment (APPENDIX A), a Piagetian reasoning task (APPENDIX B) and a verbal reasoning task (APPENDIX C) adapted from the Wechsler Intelligence Scale for Children. The participants will then be randomly allocated to one of three groups: an evolution teaching group, an electricity teaching group or an unseen control group. The teaching groups will receive six one hour lessons over a six-week period. Examples of the lesson contents can be seen in APPENDIX D and E. All the participants will then be post-tested using the same assessments as at pre-test.</p>	
<p>Photographs will be taken of the written work completed by the participants and will be anonymous. No photographs will be taken of any participants. Field notes will be made by the researcher during and after each lesson.</p>	
<p>Analysis</p> <p>The assessment data will be quantitatively analysed to determine the effectiveness of the intervention. The photographs and field notes will be qualitatively analysed to determine trends in the understanding of the participants.</p>	

SECTION B continued	
<p>b) Description of participants and obtaining informed consent (200 words). When describing participants, please include</p> <ul style="list-style-type: none"> • criteria for inclusion/exclusion • method of recruitment • processes for consent to participate <p>Please ensure you attach as separate documents (if applicable, in English translation):</p> <ul style="list-style-type: none"> • Your recruitment and advertisement material e.g. a poster or brief invitation letter/ email • information for participants to read (or hear) before they agree to take part e.g. written participant information sheets or (only if applicable) oral information scripts • a document to record informed consent. Templates for written consent forms and/or oral consent scripts (in case of an oral consent process) are available from the CUREC website • a guide to interview questions (this may be a list of questions to be asked, or a preliminary scope of questions), or a sample of other instruments (such as a sample questionnaire) • (if relevant) debriefing document after participants have taken part 	
<p>Participants</p> <p>The participants will be approximately 120 primary school children in Year 6 (10-11 years old) recruited through the school they attend.</p>	
<p>Recruitment</p> <p>The Headteachers of schools previously used in the pilot studies will be approached via email with an information letter attached (APPENDIX F) describing the project and asking for permission to recruit children from their school. Further schools will be approached if necessary.</p> <p>Once permission is gained from the school parents will be given the information letter (APPENDIX G) and opt-out consent form (APPENDIX H) detailing the research and informing parents that they can opt-out by a certain date when the research will begin. Opt-out consent is appropriate as participants are not being assessed individually and evolution and electricity are topics they would normally cover in Year 6 according to the National Curriculum.</p>	
<p>Ethics</p> <p>Informed consent, using an opt-out procedure, will be gained from the parents of all children before any data is collected. At the start of the assessments the aims of the research will be explained clearly to the children. The children will be given the opportunity to ask any questions and withdraw from the lessons at any point. Times will be arranged with teachers to ensure minimal disruption is caused to the usual school day.</p>	
<p>14. What are the ethical issues connected with your research and what steps have you taken to address them? Please do not answer 'none'. The committee needs to see evidence that you have identified potential ethical issues with respect to your research and have taken steps to address them. These issues could relate to:</p> <ul style="list-style-type: none"> • your own physical and psychological safety as a researcher (please see the University's and Social Science Division's Safety in Fieldwork guidance) • participant burdens and/or risks, and • data protection/ confidentiality. <p>For more guidance on ethical issues, please see www.admin.ox.ac.uk/curec/resources/.</p>	

<p>The topic of evolution can be seen as controversial. However, this project is concerned with understanding and not belief and this is made clear in the parent information letter. The researcher is aware that this may come up during the lessons and is prepared to deal with this appropriately. Throughout the pilot studies this did not happen.</p>					
Section B continued					
15. Will you obtain informed consent according to CUREC guidelines and good practice in your discipline before participation?	<table border="1"> <tr> <td>Yes</td> <td>No</td> </tr> <tr> <td style="text-align: center;">X</td> <td></td> </tr> </table>	Yes	No	X	
Yes	No				
X					
If you have marked 'No', please give a brief explanation and justification for this decision here:					
16. Will your research involve discussing sensitive issues? This could be information relating to race or ethnic origin, political opinions, religious beliefs, physical/mental health, trade union membership, sexual life or criminal activities.	<table border="1"> <tr> <td>Yes</td> <td>No</td> </tr> <tr> <td></td> <td style="text-align: center;">X</td> </tr> </table>	Yes	No		X
Yes	No				
	X				
If you have marked 'Yes', please make sure that you have included some supporting information (as directed in question 13 of this section) showing the range of questions covering these issues.					
17. Will you ensure that personal data collected directly from participants or via a third party is held and processed in accordance with the provisions of the Data Protection Act ?	<table border="1"> <tr> <td>Yes</td> <td>No</td> </tr> <tr> <td style="text-align: center;">X</td> <td></td> </tr> </table>	Yes	No	X	
Yes	No				
X					
18. How will you ensure that any personal or sensitive data are captured, transferred and stored securely? In particular if data are to be captured electronically, please consult with your local IT department and, with respect to University IT security policies, please comment on how you will capture such data in the first instance, how you will transfer them over networks or via portable media and how and where data will be stored. For more information please see the University's web pages on research data management: http://researchdata.ox.ac.uk/university-of-oxford-policy-on-the-management-of-research-data-and-records/					
All data will be anonymous and participants will not be identified. Any data collected will be stored securely on the researcher's laptop in a password-protected file.					

SECTION C: Methods and procedures to be used		Please mark 'X'
Method used: Please ensure you have addressed any potential ethical issues related to these methods in Section 14 and in your Participant Information Sheet		
1. Analysis of existing records		<input type="checkbox"/>
2. Snowball sampling (recruiting through contacts of existing participants)		<input type="checkbox"/>
3. Use of casual or local workers e.g. interpreters		<input type="checkbox"/>
4. Participant observation		X
5. Covert observation		<input type="checkbox"/>
6. Observation of specific organisational practices		<input type="checkbox"/>
7. Participant completes questionnaire in hard copy		<input type="checkbox"/>
8. Participant completes online questionnaire or other online task		<input type="checkbox"/>
9. Using social media		<input type="checkbox"/>
10. Participant performs paper and pencil task		X
11. Participant performs verbal or aural task (e.g. for linguistic study)		<input type="checkbox"/>
12. Focus group		<input type="checkbox"/>
13. Interview		<input type="checkbox"/>
14. Audio recording of participant (you will generally need specific consent from participants for this)		<input type="checkbox"/>
15. Video recording of participant (you will generally need specific consent from participants for this)		<input type="checkbox"/>
16. Photography of participant (you will generally need specific consent from participants for this)		<input type="checkbox"/>
17. Others (please specify):		<input type="checkbox"/>

SECTION D: Professional guidelines and training		Please mark 'X'
<p>In this section, please mark 'X' against at least one of the following professional guidelines you aim to adhere to.</p> <p>You should use the principles listed in your chosen guideline(s) in conducting your own research.</p> <p>Note: this is not an exhaustive list.</p>		
Research specialism/methodology	Association and guidance document	
Anthropology	Association of Social Anthropologists of the UK and Commonwealth	<input type="checkbox"/>
Criminology	British Society of Criminology: Code of Ethics for Researchers in the Field of Criminology	<input type="checkbox"/>
Education	Field Educational Research Association Ethical Guidelines for Educational Research	X
Geography	Association of American Geographers Statement on Professional Ethics	<input type="checkbox"/>
History	Royal Geographical Society: Research Ethics and Code of Practice	<input type="checkbox"/>
Internet-based Research	Oral History Society of the UK Ethical Guidelines	<input type="checkbox"/>
Law (Socio-Legal)	British Psychological Society: Conducting Research on the Internet	<input type="checkbox"/>
Management	Association of Internet Researchers Ethics Guide	<input type="checkbox"/>
Political Science	Also see our Best Practice Guidance on Internet-based research	<input type="checkbox"/>
Politics	Socio-Legal Studies Association: Statement of Principles of Ethical Research	<input type="checkbox"/>
Psychology	Academy of Management's Professional Code of Ethics	<input type="checkbox"/>
Social Research	American Political Science Association (APSA) Guide to Professional Ethics in Political Science	<input type="checkbox"/>
Sociology	Political Studies Association: Guidelines for Good Professional Conduct	<input type="checkbox"/>
Visual Research	British Psychological Society Code of Ethics and Conduct	<input type="checkbox"/>
Other professional guidelines. Please specify the other guidelines used here:	British Psychological Society: Conducting Research on the Internet	<input type="checkbox"/>
	Also see "Internet-based Research" guidance above	<input type="checkbox"/>
	Social Research Association: Ethical Guidelines	<input type="checkbox"/>
	The British Sociological Association: Statement of Ethical Practice	<input type="checkbox"/>
	ESRC National Centre for Research Methods Review Paper: Visual Ethics: Ethical Issues in Visual Research	<input type="checkbox"/>
<p>Please indicate what training in research ethics the researchers involved with this study have received, e.g. the title of the course and date completed (online training available at www.admin.ox.ac.uk/curec/training).</p> <p>If no formal training has been undertaken, please indicate any discussions of research methodology between researchers and supervisors here.</p> <p>Training on ethics received, in person, by Dr. David Mills at the Department of Education, University of Oxford on November 20th 2013 in a Foundations of Education Research session.</p>		

SECTION E: Signatures

- Electronic signatures sent as email confirmations from a University of Oxford email address can be accepted. Separate emails should come from each of the relevant signatories as outlined below, indicating acceptance of the relevant responsibilities.
- If you have obtained handwritten (wet-ink) signatures, please scan them and the rest of the checklist pages to create a single PDF document and email through.


Please ensure this checklist is signed by:

For staff research:	For student research:
1. <u>Principal researcher</u>	1. <u>Principal researcher (project supervisor)</u>
2. <u>Head of Department (or nominee)</u>	2. <u>Head of Department (or nominee)</u>
	3. <u>Student researcher</u>

1. **Principal researcher/signature/supervisor signature (if student research)**

I understand my responsibilities as Principal Researcher as outlined in the CUREC glossary and guidance on the CUREC website.

I declare that the answers above accurately describe the research as presently designed, and that a new checklist will be submitted should the research design change in a way which would alter any of the above responses so as to require completion of CUREC 2 (involving full scrutiny by an IDREC). I will inform the relevant IDREC if I cease to be the principal researcher on this project and supply the name and contact details of my successor if appropriate.

Signature: 

Print name (block capitals):JUDITH HILLIER..... Date:5th OCTOBER 2016.....

2. **Departmental endorsement signature**

I have read the research project application named above. On the basis of the information available to me, I:

(i) consider the principal researcher to be aware of her/his ethical responsibilities in regard to this research;

(ii) consider that any ethical issues raised have been satisfactorily resolved or are covered by relevant professional guidelines and/or CUREC approved procedures, and that it is appropriate for the research to proceed (noting the principal researcher's obligation to report should the design of the research change in a way which would alter any of the above responses so as to require completion of a CUREC 2 (full application));

(iii) am satisfied that the proposed project design and scientific methodology is sound; the project has been/will be subject to appropriate peer review; and is likely to contribute to existing knowledge and/or to the education and training of the researcher(s) and that it is in the public interest.

Signed by **Head of Department or nominee** (example nominees for student research include the Director of Graduate Studies/ Director of Undergraduate Studies):

Signature: Date:
 Print name (block capitals): Date:
 3. **Student signature (if student research)**

I understand the questions and answers that have been entered above describing the research, and I will ensure that my practice in this research complies with these answers, subject to any modifications made by the principal researcher properly authorised by the CUREC system.

Signed by student: Date:5th OCTOBER 2016.....
 Print name (block capitals):JENNIFER MCGOWAN-SMYTH.....

Appendix D: School consent letter

UNIVERSITY OF OXFORD

DEPARTMENT OF EDUCATION

15 Norham Gardens, Oxford OX2 6PY

Phone +44 (0) 1865 274024 Fax +44 (0) 1865 274027

general.enquiries@education.ox.ac.uk <http://www.education.ox.ac.uk>

Director: Professor Jo-Anne Baird



The teaching of evolution at primary school

Dear Headteacher,

I am a DPhil (PhD) student at Oxford University and am writing to enquire about carrying out a study in your school during the autumn term 2016. The study aims to investigate how effective a series of evolution lessons are for 10-11 year-old children. This topic was included in the new national curriculum as one of the big ideas in science, but there is little research on how primary school children think about evolution and what difficulties they will have when they are taught about it. I worked as a qualified Science teacher in an Oxfordshire secondary school for three years before commencing my research project, and would very much like to see my project making a contribution to the teaching of science.

The participants will be Year 6 children and they will all complete a series of tasks to determine their existing understanding about evolution. The children will then be allocated to one of three groups. One group will be taught six hour-long lessons about evolution and another group will be taught six hour-long lessons about electricity. Photographs of the children's work and field notes will be taken. The final group will not receive any teaching. All children will then complete another series of tasks to investigate whether their understanding has changed.

The parent/guardian of each child will be given the opportunity to opt-out on behalf of their child. The opt-out consent form is appended for your analysis. The research will also be explained to the children to obtain their agreement to participate and they will know that they may withdraw at any point during the study.

Care will be taken to arrange an appropriate time with teachers, so that there is minimal disruption to the teaching day. The data collected for this research will be anonymised and kept in accordance with the Data Protection Act. No information on individual students will be available. At the end of the study, I will send you a brief summary of the results. The study has been cleared by the University of Oxford Central University Research Ethics Committee. I have Disclosure Barring Service (DBS, UK) clearance to work with children.

The University of Oxford is committed to the dissemination of research for the benefit of society and has an online archive where completed DPhil theses are stored. This project will be written up as a thesis and will be deposited in the print and online archives for future access by researchers.

I hope your school will be interested in participating in this research. If you need more information about the study and your school's involvement in it, please feel free to contact me, by sending an email to jennifer.mcgowan-smyth@education.ox.ac.uk, or to my supervisors Professor Terezinha Nunes (terezinha.nunes@education.ox.ac.uk) or Dr Judith Hillier (judith.hillier@education.ox.ac.uk).

Thank you very much for taking the time to read this letter. I am looking forward to hearing back from you via email and I will call to clarify any doubts you may have.

Yours sincerely,

Jennifer McGowan-Smyth

Email: jennifer.mcgowan-smyth@education.ox.ac.uk

Web: <http://www.education.ox.ac.uk/about-us/directory/jennifer-mcgowan-smyth/>

Appendix E: Parent consent letter

UNIVERSITY OF OXFORD

DEPARTMENT OF EDUCATION

15 Norham Gardens, Oxford OX2 6PY

Phone +44 (0) 1865 274024 Fax +44 (0) 1865 274027

general.enquiries@education.ox.ac.uk <http://www.education.ox.ac.uk>

Director: Professor Jo-Anne Baird



November 2016

Teaching evolution at primary school

Dear Parent/Guardian,

I am a DPhil (PhD) student at Oxford University and am currently researching primary school children's ideas about evolution, which is now part of the National Curriculum. I worked as a qualified Science teacher for three years before commencing my research project so I have a personal interest in this research as well as recent experience working in schools and teaching children.

Your child's school has agreed to take part in the research and I am writing to you to invite your child to participate in this project. Please take time to read the following information carefully.

What is the research project about?

Evolution was added to the National Curriculum at Primary School for the first time in September 2014. The project aims to find out whether a series of lessons to teach evolution are enjoyable for children and if the activities are effective.

Why has my child been invited to participate?

Your child's school has agreed to participate in the project. According to the National Curriculum evolution should be taught in Year 6 and your child would normally be taught evolution by their teacher this year.

What will my child have to do?

Your child will be asked to complete a pen and paper questionnaire with questions about living things and looking at similarities between objects. They will also look at some practical tasks and answer questions about what they see. The tasks will be presented in class and it should take around 90 minutes in total to complete all tasks. The time for these activities will be agreed with the teacher to cause minimum disruption to the usual school day.

Your child may then take part in a series of six, hour-long science lessons where they are taught about evolution or electricity by the researcher who is a qualified science teacher. Photographs may be taken of their work but all work will be anonymous and your child will not be identifiable. Another series of tasks will then be completed by all children.

Does my child have to participate?

If you do not wish your child to participate you can return the opt-out form attached to this letter. Your child will also be asked if he/she wants to participate. The opt-out form needs to be returned by **Monday November 21st 2016**.

What will happen to the data collected?

No individual data will be collected from your child and any photographs taken of their work will be used to help the researcher to understand whether the lessons are effective and enjoyable for the children.

The data collected for this research will be kept in accordance with the Data Protection Act 1998. No information about specific children will be included in the analysis. The University of Oxford is committed to the dissemination of research for the benefit of society and has an online archive where completed DPhil theses are stored. This project will be written up as a thesis and will be deposited in the print and online archives for future access by researchers.

Who has reviewed this project?

This project has been reviewed by, and received ethics clearance through, the University of Oxford Central University Research Ethics Committee (CUREC) and has been thoroughly discussed with my supervisors. I have Disclosure Barring Service (DBS, UK) clearance to work with children.

Who do I contact if I have questions?

If you have any questions at all or require any further information about the project or your child's participation do not hesitate to contact either myself or my supervisors at any time using the email addresses below:

Researcher: Jennifer McGowan-Smyth jennifer.mcgowan-smyth@education.ox.ac.uk

Supervisor: Professor Terezinha Nunes terezinha.nunes@education.ox.ac.uk

Supervisor: Dr Judith Hillier judith.hillier@education.ox.ac.uk

What do I need to do next?

If you would like your child to participate in the study you do not need to do anything. If you **do not** want your child to participate you need to return the opt-out form attached to this letter by **Monday November 21st 2016**. If the form is not received by this date your child will take part in the project with the researcher.

I hope your child will be interested in participating in this research. Please do not hesitate to get in contact if you require any further information using the contact details above.

Thank you very much for taking the time to read this letter.

Yours sincerely,

Jennifer McGowan-Smyth

Email: jennifer.mcgowan-smyth@education.ox.ac.uk

Web: <http://www.education.ox.ac.uk/about-us/directory/jennifer-mcgowan-smyth/>

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general.enquiries@education.ox.ac.uk <http://www.education.ox.ac.uk>

Director: Professor Jo-Anne Baird



Teaching evolution at primary school – OPT OUT Form

This form needs to be returned if you **DO NOT** want your child to participate in the project with the researcher. Please return the form to your child's class teacher by **Monday November 21st 2016.**

I do not give permission for my child to take part in the study, 'teaching evolution at primary school'.

Name of child _____

Parent/Guardian name (block capitals) _____

Parent/Guardian signature _____ Date: _____

Appendix F: Justification scoring protocol

Hawkfish

The **bold** statement is the type of answer expected and the *italicised* examples have been taken directly from the assessments or edited slightly to make the example clearer.

0 : no justification given

- *I don't know*
- *I guessed*
- *It seems likely*

Q1 - Variation

1 : incorrect justification given

All identical or completely different

- *All be completely different like fingerprints*
- *You will not see any differences at all*

These examples are not an exhaustive list, as participant's responses varied considerably.

2 : correct description which may contain some incorrect ideas

Variation acknowledged but reasons not given

- *I think they would look similar but not identical*
- *The patterns wouldn't be exactly the same*

3 : correct explanation without vocabulary

Variation acknowledged and the genetic and/or environmental causes mentioned

- *Every human is slightly different as their parents are different so it is the same for the fish*
- *There would be some differences between the fish as the environment may have an impact*

4 : correct explanation with correct use of vocabulary

Variation acknowledged and the genetic and/or environmental causes mentioned using vocabulary (genes, environment, inherited)

- *There are differences between the fish as they will have inherited different genes from different parents*
- *If the fish are all the same species there might be some differences due to different genes or the environment*

Q2 - Inheritance

1 : incorrect justification given

Age or the environment is the only cause of their appearance

- *The stripes will only come when they are adults*
- *They aren't in their right habitat so they won't have the same as their parents*

These examples are not an exhaustive list, as participant's responses varied considerably.

2 : correct description which may contain some incorrect ideas

Traits are inherited by offspring but may mention age or environment as being the cause

- *Babies often look similar to their parents*
- *They will get half the stripes from their parents but not all of them as they are in a different habitat*

3 : correct explanation without vocabulary

They will still have their parent's genetic information and any adaptive changes will not be seen in one generation

- *It doesn't matter if there isn't coral as the fish are the same colour as their parents*
- *Over the years the fish have had red stripes so it won't change suddenly*

4 : correct explanation with correct use of vocabulary

They will still have their parent's genetic information and any adaptive changes will not be seen in one generation using vocabulary (generation, genes, environment)

- *It takes many generations for an animal to completely change its markings by adapting to the environment*
- *They will get their parent's genes but this will change over generations if they stay in the same environment*

Q3 - Adaptation

1 : incorrect justification given

Changes are attributed only to the environment

- *They rely on the coral to keep them alive*
- *Something in their diet makes them red*

These examples are not an exhaustive list, as participant's responses varied considerably.

2 : correct description which may contain some incorrect ideas

Mentioned surviving longer (or shorter) or having more babies but did not link them together

- *All the fish without stripes will die*
- *They lived for longer and had more babies like them*

3 : correct explanation without vocabulary

Survive for longer and reproduce more, offspring will inherit the beneficial trait

- *They cannot control their colour but the stripes will be passed on if they survive longer*
- *The baby fish will have more stripes if their parents were better camouflaged*

4 : correct explanation with correct use of vocabulary

Survive for longer and reproduce more, offspring will inherit the beneficial trait using vocabulary (offspring, reproduce, inherited)

- *If they survived for longer they could produce more offspring and the offspring would inherit the stripes from their parents*
- *The fish that had some stripes would have had more offspring which inherited the stripes*

Q4 - Speciation

1 : incorrect justification given

Species are only related to similar species or that many species evolved into a hawkfish

- *All the ancestors evolved into hawkfish*
- *Maybe a goldfish turned into a hawkfish*

These examples are not an exhaustive list, as participant's responses varied considerably.

2 : correct description which may contain some incorrect ideas

Not recognising that a common ancestor exists and only describing closely related species as similar

- *They live around other tropical fish so they will be related*
- *The distances in the sea are too big for them to be related to species they don't live near*

3 : correct explanation without vocabulary

The hawkfish has evolved from the same ancestor as other species as the fish adapted to their different environments.

- *Over time the ancestor will have developed into new fish in different environments*
- *Different fish have come from one type of fish that lived a long time ago*

4 : correct explanation with correct use of vocabulary

The hawkfish has evolved from the same ancestor as other species as the fish adapted to their different environments using vocabulary (common ancestor, species, adapted)

- *Some fish will have adapted to the open ocean and some to coral reefs so they will end up different species*
- *All fish species will share a common ancestor that all the fish species alive have evolved from*

Q5 - Domestication

1 : incorrect justification given

Size being caused purely by the environment or just changing without human intervention

- *You need food to grow so they will be smaller if they eat less*
- *They will just have smaller babies naturally*

These examples are not an exhaustive list, as participant's responses varied considerably.

2 : correct description which may contain some incorrect ideas

Smaller offspring are produced without clearly describing the role of humans

- *Then the babies will be twice as small*
- *The offspring will be smaller if the parents are smaller*

3 : correct explanation without vocabulary

Trait being inherited and mention of human intervention (let them breed, then they breed) without vocabulary

- *If smaller fish are allowed to breed together you're more likely to get smaller fish*
- *Over time they will change if you only breed specific ones*

4 : correct explanation with correct use of vocabulary

Trait being inherited and mention of human intervention (let them breed, then they breed) with vocabulary (inherited, offspring)

- *The offspring would inherit some of the size from their parents and over generations only letting the smallest breed would reduce the size*
- *The size is inherited and then the pet shop can breed the two smallest offspring and so on*

Q6 - Extinction

1 : incorrect justification given

Extinctions happening naturally are rare and mainly caused by humans

- *Humans cause extinctions*
- *Animals will adapt before they go extinct*

These examples are not an exhaustive list, as participant's responses varied considerably.

2 : correct description which may contain some incorrect ideas

An example of a natural cause of extinction described

- *Lots of animals go extinct from diseases*
- *Another fish ate all the hawkfish food*

3 : correct explanation without vocabulary

Species go extinct naturally when the population decreases without human intervention and it is more likely than adaptation

- *One fish gets the disease and then spreads the disease to other fish reducing the numbers*

4 : correct explanation with correct use of vocabulary

Species go extinct naturally when the population decreases without human intervention and it is more likely than adaptation using vocabulary (adapt, reproduce, population)

- *A disease reduced the number of hawkfish so there were not enough individuals left to reproduce*
- *The species did not have enough time to adapt to the new predators/disease so they went extinct*

Cacti

The **bold** statement is the type of answer expected and the *italicised* examples have been taken directly from the assessments or edited slightly to make the example clearer.

0 : no justification given

- *I don't know*
- *I guessed*
- *It seems likely*

Q1 - Variation

1 : incorrect justification given

All identical or completely different

- *All be completely different*
- *They only don't look the same because they are different species*

These examples are not an exhaustive list, as participant's responses varied considerably.

2 : correct description which may contain some incorrect ideas

Variation acknowledged but reasons not given

- *Some may have more spines than others*
- *They grow slightly differently and wouldn't be exactly the same*
- *All things are similar but different*

3 : correct explanation without vocabulary

Variation acknowledged and the genetic and/or environmental causes mentioned

- *They won't be exactly the same as they might live in different soil and have different amounts of water*
- *They grew differently as they came from different seeds*

4 : correct explanation with correct use of vocabulary

Variation acknowledged and the genetic and/or environmental causes mentioned using vocabulary (genes, environment, inherited)

- *There are differences between the cacti as some seedlings will have inherited different genes to other seedlings*
- *If the cacti are all the same species there might be some differences due to different genes or the amount of food they had*

Q2 - Domestication

1 : incorrect justification given

Size being caused purely by the environment or just changing without human intervention

- *Cutting them off will encourage them to leave*
- *Smaller spines won't hurt as much*

These examples are not an exhaustive list, as participant's responses varied considerably.

2 : correct description which may contain some incorrect ideas

Offspring with smaller spines are produced without clearly describing the role of humans

- *The offspring of the ones with smaller spines would be smaller*
- *The baby cactus would get the genes from its parents*

3 : correct explanation without vocabulary

Trait being inherited and mention of human intervention (let them breed, then they breed) without vocabulary

- *If they chose the smaller spines then the baby cactus would have smaller spines as smaller parents have smaller children*
- *The gardener should only use the seeds of the ones with smaller spines as the new cactus would then have smaller spines*

4 : correct explanation with correct use of vocabulary

Trait being inherited and mention of human intervention (let them breed, then they breed) with vocabulary (inherited, offspring)

- *If the mother and father have small spines and are allowed to reproduce then the offspring will inherit the small spines*
- *The young cacti would inherit the smaller spines from their parents, then the gardener should breed the offspring with the smallest pines and so on.*

Q3 - Adaptation

1 : incorrect justification given

Changes are attributed only to the environment

- *When you are in the sun your hair grows so maybe the spines grow in the heat*
- *They grew their spines so they survived longer*

These examples are not an exhaustive list, as participant's responses varied considerably.

2 : correct description which may contain some incorrect ideas

Mentioned surviving longer (or shorter) or having more babies but did not link them together

- *Nature would do it so they live longer*
- *They survived for longer and no animals could eat them as they were spiky*

3 : correct explanation without vocabulary

Survive for longer and reproduce more, offspring will inherit the beneficial trait

- *If only the cacti that had spines survived then eventually all the baby cacti would have spines*
- *The cacti with longer spines will get eaten less and make more seeds*

4 : correct explanation with correct use of vocabulary

Survive for longer and reproduce more, offspring will inherit the beneficial trait using vocabulary (offspring, reproduce, inherited)

- *The longer they live the more they can breed so the offspring have spines as they inherited them from their parents.*

Q4 - Speciation

1 : incorrect justification given

Species can reproduce with any other species

- *Any plant will do*
- *As long as the plant is the other gender they can breed*

These examples are not an exhaustive list, as participant's responses varied considerably.

2 : correct description which may contain some incorrect ideas

Species can only reproduce with their own species

- *Humans can't breed with dogs*
- *They are the same species*
- *With a different type of plant it would not be able to breed*

3 : correct explanation without vocabulary

Species can only reproduce with their own species to produce offspring

- *Other plants have to breed with other plants and cactus breeds with cactus to make baby cactus*
- *They wouldn't be able to breed to make other cactus with a different plant*

4 : correct explanation with correct use of vocabulary

Species can only reproduce with their own species to produce offspring using vocabulary (species, offspring, reproduce)

- *The cactus can only breed with its own species to create young*
- *It is only possible for a species to reproduce with its own species to produce offspring*

Q5 - Extinction

1 : incorrect justification given

Extinctions happening naturally are rare and mainly caused by humans

- *Humans don't want anyone to hurt themselves so they killed them*
- *Species will never stop adapting*

These examples are not an exhaustive list, as participant's responses varied considerably.

2 : correct description which may contain some incorrect ideas

An example of a natural cause of extinction described

- *If other plants ate all the food and water the cacti would not be able to get any*
- *It would be difficult to survive without water*

3 : correct explanation without vocabulary

Species go extinct naturally when the population decreases without human intervention and it is more likely than adaptation

- *The conditions changed so no more cactus could grow*
- *A lack of food might kill most of the cacti and then the rest couldn't live*

4 : correct explanation with correct use of vocabulary

Species go extinct naturally when the population decreases without human intervention and it is more likely than adaptation using vocabulary (adapt, reproduce, population)

- *Different conditions in the environment reduced the number of cacti so there were not enough individuals left to reproduce*
- *The species did not have enough time to adapt to the new predators/disease so they went extinct*

Q6 - Inheritance

1 : incorrect justification given

Age or the environment is the only cause of their appearance

- *The baby plants would have adapted to their new environment*
- *They would look like new plants*
- *They are in a new country so you cannot tell*

These examples are not an exhaustive list, as participant's responses varied considerably.

2 : correct description which may contain some incorrect ideas

Traits are inherited by offspring but may mention age or environment as being the cause

- *They are still the same species*
- *Over time they might camouflage but to start with they would look like cactus*

3 : correct explanation without vocabulary

They will still have their parent's genetic information and any adaptive changes will not be seen in one generation

- *They can't just magically turn into different plants, they are still cactus plants*
- *Just because something moves where it lives doesn't mean it will change what it looks like*
- *The environment wouldn't change what they are*

4 : correct explanation with correct use of vocabulary

They will still have their parent's genetic information and any adaptive changes will not be seen in one generation using vocabulary (generation, genes, environment)

- *It takes many generations for a plant to grow spines by adapting to the environment*
- *They will get their parent's genes but this will change over generations if they stay in the same environment*

Curlew

The **bold** statement is the type of answer expected and the *italicised* examples have been taken directly from the assessments or edited slightly to make the example clearer.

0 : no justification given

- *I don't know*
- *I guessed*
- *It seems likely*

Q1 - Variation

1 : incorrect justification given

All identical or completely different

- *All be unique*
- *You will not see any differences at all*

These examples are not an exhaustive list, as participant's responses varied considerably.

2 : correct description which may contain some incorrect ideas

Variation acknowledged but reasons not given

- *Some might be fatter than others*
- *Some might have longer beaks than others*

3 : correct explanation without vocabulary

Variation acknowledged and the genetic and/or environmental causes mentioned

- *Every bird is slightly different because it matters what their parents look like*
- *Their parents beaks change what their own looks like*

4 : correct explanation with correct use of vocabulary

Variation acknowledged and the genetic and/or environmental causes mentioned using vocabulary (genes, environment, inherited)

- *There are differences between the birds as they will have inherited different genes from their parents*
- *They will inherit genes that would make the beaks longer*

Q2 - Domestication

1 : incorrect justification given

Speed being caused purely by the environment or just changing without human intervention

- *If you train them properly they will be really good at running*
- *If you let them learn themselves they will teach themselves to become faster*

These examples are not an exhaustive list, as participant's responses varied considerably.

2 : correct description which may contain some incorrect ideas

Faster offspring are produced without clearly describing the role of humans

- *Then they will be much faster*
- *The offspring will be faster if the parents are faster*

3 : correct explanation without vocabulary

Trait being inherited and mention of human intervention (let them breed, then they breed) without vocabulary

- *If you breed the faster ones the chicks will be faster*
- *Breeding the fastest ones will make the baby ones faster than others*

4 : correct explanation with correct use of vocabulary

Trait being inherited and mention of human intervention (let them breed, then they breed) with vocabulary (inherited, offspring)

- *They will be as fast as their parents because of the genes they inherited*
- *The speed is inherited and then they can breed the two smallest offspring and so on*

Q3 - Inheritance

1 : incorrect justification given

Age or the environment is the only cause of their appearance

- *It doesn't matter about their parents at all*
- *Their beak size will be random so you cannot tell*

These examples are not an exhaustive list, as participant's responses varied considerably.

2 : correct description which may contain some incorrect ideas

Traits are inherited by offspring but may mention age or environment as being the cause

- *The parent's weren't born with shorter beaks*
- *It doesn't matter that the beaks broke off as the eggs may have already been laid*

3 : correct explanation without vocabulary

They will still have their parent's genetic information and any adaptive changes will not be seen in one generation

- *Their parents were born with longer beaks and that won't suddenly change*
- *The parent's beaks only broke off in the sand so the babies will still have longer beaks*

4 : correct explanation with correct use of vocabulary

They will still have their parent's genetic information and any adaptive changes will not be seen in one generation using vocabulary (generation, genes, environment)

- *The broken beaks were caused by the environment and not genetics*
- *They will inherit the genes and the environmental change will not make a difference*

Q4 - Extinction

1 : incorrect justification given

Extinctions happening naturally are rare and mainly caused by humans

- *They will adapt to their new environment*
- *The environment wouldn't affect the curlews*

These examples are not an exhaustive list, as participant's responses varied considerably.

2 : correct description which may contain some incorrect ideas

An example of a natural cause of extinction described

- *They might not be able to adapt quick enough*
- *Another bird was bigger and ate the curlew's food*

3 : correct explanation without vocabulary

Species go extinct naturally when the population decreases without human intervention and it is more likely than adaptation

- *They wouldn't be camouflaged and many of the birds wouldn't survive anymore*
- *There were other animals better adapted so they out-competed the curlews*

4 : correct explanation with correct use of vocabulary

Species go extinct naturally when the population decreases without human intervention and it is more likely than adaptation using vocabulary (adapt, reproduce, population, competition)

- *There were other animals better adapted so they out-competed the curlews*
- *The species did not have enough time to adapt to the new predators/disease so they went extinct*

Q5 - Adaptation

1 : incorrect justification given

Changes are attributed only to the environment

- *The beaks will stretch*
- *Maybe the crabs all ran away*

These examples are not an exhaustive list, as participant's responses varied considerably.

2 : correct description which may contain some incorrect ideas

Mentioned surviving longer (or shorter) or having more babies but did not link them together

- *They can catch more fish in deeper water so will have more food*
- *Then they could survive for longer*

3 : correct explanation without vocabulary

Survive for longer and reproduce more, offspring will inherit the beneficial trait

- *Some birds will have longer beaks and the baby birds will too*
- *The ones with shorter beaks would catch fewer crabs and die out before they had babies*

4 : correct explanation with correct use of vocabulary

Survive for longer and reproduce more, offspring will inherit the beneficial trait using vocabulary (offspring, reproduce, inherited)

- *The longer beaks will be in the genetics and be passed on*
- *They will inherit the genes from their parents who lived for longer and would reproduce more*

Q6 - Speciation

1 : incorrect justification given

The birds would stay the same or adapt to the environment quickly

- *They would just get used to their environment*
- *Adaptation is common in animals*

These examples are not an exhaustive list, as participant's responses varied considerably.

2 : correct description which may contain some incorrect ideas

Recognising that new species may appear but suggests they can still breed with each other or adapt over a longer period of time

- *They are similar birds that now live in different environments*
- *As long as there is at least 1 male and 1 female they will be able to breed with each other*
- *They will still be able to breed, the environment won't change this*

3 : correct explanation without vocabulary

The groups would become different species and no longer be able to breed with the other group

- *They might have become different types that are too different to have babies*
- *It might take a while to adapt and become different enough so they cannot reproduce*

4 : correct explanation with correct use of vocabulary

The groups would become different species and no longer be able to breed with the other group using vocabulary (species, speciation, reproduce, offspring)

- *They will have adapted to their new environments and will no longer be able to breed with each other to produce offspring*
- *Eventually the species would become different from each other and if they are no longer the same species they cannot have offspring*