Understanding Evolution and Inheritance

in the National Curriculum KS2-KS3

Final Report of Project: EDU/42298
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EXECUTIVE SUMMARY

Context

This report presents a summary of work carried out under the Nuffield Foundation's Project: EDU/42298 in terms of dissemination activities and outputs. Because of the extent of project activities, the empirical findings are only briefly described. This report references all related results from empirical project activities to date. Related research and dissemination activities and outputs are also referenced, where more detailed descriptions can be located.

1. Project Objectives

A new national curriculum for science in England was introduced to all year groups from September 2016 and the implementation of the new area of Evolution and Inheritance was expected to bring novel challenges, particularly at KS2. The project undertook to conduct research that would inform and support all stakeholders' understanding of the implications: KS2-3 teachers, children, policymakers, curriculum and assessment developers and others. Our previous study funded by the Nuffield Foundation (Evolution & Inheritance Project, Study 1, Nuffield Foundation grant reference EDO/41491), provided evidence that included children's conceptual difficulties with macroevolution. In the context of discussions about inheritance, the researchers noted that some KS2 pupils referred to DNA, albeit this was beyond the remit and expectation of the formal curriculum. The more general and overall conclusion from Study 1 was that much more attention and support was required for progression in understanding Evolution and Inheritance, both within Key Stage 2 and in the transition across to Key Stage 3. The intended foci for the Study 2 research were three specific areas where curriculum and pedagogy at the KS2-3 transition hold the prospect of novel and useful insights to inform the introduction of improved continuity and progression into teaching and learning.

Focus i): Macroevolution. The project explored the extent to which encouraging pupils' metacognitive reflection – that is, thinking about their own thinking - on the meaningfulness to them of a variety of relevant 2-D and 3-D representations might support a 'big picture' or macroscopic view of evolution. In addition, this focus also helped to link Studies 1 and 2 by supporting construction of an overall Darwinian framework for the KS1-2 biology curriculum.

Focus ii): DNA. The intention was to explore pupils' informal understandings about DNA as garnered from entertainment and other broadcast media. This information would be used to consider the implications for understanding of inheritance together with any implications for the curriculum in the KS2-KS3 transition.

Focus iii): Working scientifically using argumentation. The intention in this aspect of the research was to explore what can be learned about the successes (and ways of building on these) and difficulties (and ways of obviating or finding positive solutions to these) of managing scientific discourse activities across KS2-3 in the conceptual domains (ideas about macroevolution and DNA) that were the focus of this enquiry.

2. Project methods

A sample of twelve teachers across the Years 5-9 (age 9 to 14) range was drawn from primary and secondary schools in the Northwest of England from an assortment of urban and rural catchment areas, informed by contacts with Local Authority personnel. The sample teachers were identified as having expressed an interest and motivation to engage in classroom research.

A range of enquiry methods was adopted according to the needs of the various aspects of the research. To explore effective strategies for approaching the teaching and learning of macroevolution, teachers were invited to introduce all pupils to six different representations of the Tree of Life metaphor. Interviews were conducted by the researchers with a sample of six pupils drawn from each class, stratified by gender and overall attainment. Pupils were selected for interview by their teacher to ensure as far as possible, three males and three females each of low, medium and high overall attainment. This procedure resulted in a sample of 72 pupils (see Table 1) who were interviewed individually by one or other of the two university-based researchers. (The interview protocol is reproduced as Appendix 1.)

Table 1. Number of teachers and pupils involved in the project

	Y5	Y6	Y7	Y8	Y9	Total
Number of teachers/classes	2	3	3	3	1	12
Pupil interviews (sub-sample)	12	18	18	18	6	72
Pupils responding to DNA questionnaire (all)	41	76	77	83	21	298*
Number of pupils completing rating scales (all)	40	63	80	83	45	311*
Classroom activities (all)	41	76	80	83	45	325*

**Data were collected at different times and the presence of all pupils on all occasions could not be assured. Table 1 contains the base figures for subsequent percentages relating to year group responses to the DNA questionnaire and rating scales. While the samples for Years 5 and 9 are comparatively small, for consistency, percentages have been included for all year groups.*

A structured questionnaire (Appendix 2) was used to elicit all pupils' (in participating classes or science sets) awareness of DNA (*n*=298). It was emphasised to pupils that this procedure was not a test, but a means of finding out their existing ideas as gathered from everyday sources. The collection, coding and subsequent analysis of pupils' ideas about DNA involved responses from all pupils in the project classes.

Teachers arranged class discussion sessions following all pupils' collection of evidence for beliefs about macroevolution and DNA. All pupils present (*n*=311) and teachers (*n*=12) completed a rating scale that probed their views about the value of various aspects of discussion to science learning. The total number of pupils in each class or set responding to the questionnaire and rating scale varies as pupils completed these on different occasions and the number of pupils present on the different occasions varied.

3. Key Findings

3.1 Macroevolution

Despite initial unfamiliarity with cladograms – branching diagrams showing the relationship between species as they have evolved from most recent common ancestors into different species over millions of years - teachers welcomed unanimously the suggested innovation of their introduction at around the time of the primary-secondary transition. Almost all (94%) of those pupils interviewed suggested that the simplified primate cladogram helped their understanding of evolution. Studies 1 and 2 enabled the researchers to construct a curriculum map for KS1-2, including introduction to cladograms, (see Table 2, page 14).

Introducing a variety of representations of the Tree of Life metaphor (reproduced as Figures 1-6 on page 11) consolidated the notion of macroevolution by providing pupils with the opportunity to reflect upon and to discuss, using evidence-based exchanges, the affordances or weaknesses of each formulation and translations between them.

3.2 Pupils' ideas about DNA

The premise, confirmed by this research, had been that pupils construct an awareness of DNA through their exposure to popular media. While the concept is not included in the KS2 science curriculum, half the pupils responding to the questionnaire in Y5 (54%) and four-fifths (79%) in Y6 demonstrated awareness of DNA in their responses. They showed awareness of how DNA might be used by police (for forensic identification) and how DNA might be used by medical professionals (to identify family members and to treat and cure diseases).

Younger pupils tended to hold macroscopic ideas about the location of DNA in the body, suggesting it could be found in 'hair' or 'skin'. In contrast, microscopic responses describing DNA as being located in cells, increased with age, reflecting exposure to the KS3 biology curriculum.

Small proportions of pupils at Year 5 (12%) and 6 (20%) revealed awareness that DNA can cross generations. The proportions expressing this belief gradually increased with age so that by Year 9, almost two-thirds (62%) explicitly expressed awareness of the transfer of DNA from parents to offspring.

A possible link with experience of the function of computer software was inferred when understanding of DNA's mechanism was expressed by pupils as a set of 'instructions'. There was an age-related increase in this interpretation, with only a single pupil in Years 5 and 6 and two pupils in Year 7 describing DNA as having an instructional function, rising to a quarter (24%) of Y8 and two-thirds (67%) of Year 9 pupils.

It is a fact that the Human Genome project (2003) has enormous implications for peoples' lives as well as the future of scientific research. However, the majority of pupils (93%) showed no awareness of this programme of research, despite its social and scientific significance.

Currently, the educational implications for understanding DNA's function in the primary phase converge around several far-reaching developments. Genome editing is moving closer to therapeutic intervention. Public understanding needs to be kept abreast of 'rewriting the human genetic code'. Young people are gaining life-world awareness of ways in which DNA can provide significant evidential influence on real world issues. Important educational innovations in the Computing and Personal, Social and Health Education (PHSE) curricula have the potential to reinforce both the metaphor and the mechanism of DNA's role in inheritance.

Currently, the late primary to early secondary science curriculum in England does not support the basis for beginning to comprehend DNA's role. Some steps are missing to arrive at a developmental learning progression (DLP) offering continuity in pupils' understanding. Yet such an approach is feasible. The primary to secondary transition is suggested to be an appropriate time to introduce the currently missing core concepts of the cell, containing a controlling nucleus in which DNA acts as a code, and cell division as a key feature of sexual reproduction. Relationship and sex education (RSE) introduces terms including 'egg' and 'sperm', these special cells carrying only half the code as compared with other cells in the body. The introduction of these ideas can be framed in a manner that helps pupils to make better sense of knowledge about DNA gained from out-of–school sources and could smooth progression in science learning about inheritance. The innovation of introducing these conceptual steps to facilitate pupils' appreciation of the role of DNA is logically compelling.

3.3 Argumentation

Argumentation practices (as these are currently understood in science education research) were not embedded in project teachers' habitual approaches to working scientifically. In the course of the project, teachers developed strategies designed to encourage pupils' active identification, evaluation and use of information as evidence to support claims.

On reflection, almost all pupils (95%) and all of their teachers agreed that they found this form of discussion helpful to pupils' science understanding. Illustrative responses suggest pupils believed they modified their ideas during these discussions.

4. Implications and Recommendations for Policy and Practice

Our programme of research was intended, first and foremost, to generate evidence-based practical advice for the teaching and learning of a Darwinian perspective on evolution and inheritance across the years of primary to secondary transition. Various strategies in pursuit of this aim are set out below.

A Darwinian curriculum framework. A major outcome of the research is a curriculum framework for evolution and inheritance (see Table 2, p.14) that has a consistent Darwinian underpinning. This 'road map' incorporates developmental learning progressions (DLPs) and offers teachers practical suggestions for introducing and developing incrementally the key concepts within evolution and inheritance to support progression across Key Stages 1 and 2 and transition to KS3. The early introduction of macroevolution to pupils in Y5-6 along with the use of a range of representations of the Tree of Life is advocated on the basis of the research, with pupils encouraged to use discussion to translate between different formats or models.

A Developmental Learning Progression for understanding Inheritance. Pupils' awareness of DNA and its technical application in forensics, in identifying disease and in establishing family relationships was confirmed even amongst some of the younger pupils in the sample, those in years 5 and 6. Earlier introduction of the concept of the cell is recommended along with strategies that encourage pupils to think of DNA within the cell nucleus as a set of instructions (like computer software code) that transfers from one generation to the next. Significant educational innovations within the Computing curricula in the form of a renewed emphasis on programming, coupled with proposed changes to the PSHE education curriculum, have the potential to reinforce both the metaphor and the scientific mechanism of DNA's role in inheritance.

A practical resource to support Argumentation. An important aspect of argumentation is pupils' expression of a diverse range of claims to which other pupils can respond. The project has created audio clips of pupils' ideas that are available to teachers as a free resource at www.ideasaboutevolution.com. These clips, together with associated teacher guidance notes, are intended to be used formatively to help identify and make explicit pupils'own ideas that will provide valuable starting points for teachers' use as triggers for classroom science discourse or argumentation sessions. Dissemination of the website's availability has included hard copy notifications via Association for Science Education publications (in press), various online sites and through references in publications.

A number of outputs, summarised in Section 6 of this report, have been made possible by the Study 2 research, building on Study 1 findings. These outputs seek to ensure wide dissemination of what has been learned and help to ensure the practical implementation of the project's findings.

FINAL REPORT

1. Project Objectives

A new national curriculum for science in England was introduced to all year groups from September 2016; the implementation of the new area of Evolution and Inheritance was expected to bring novel challenges to teachers and pupils, particularly at KS2. The project undertook to conduct research that would inform and support all stakeholders' understanding of the implications of Evolution and Inheritance in the National Curriculum KS2-3: teachers, children, policymakers, curriculum and assessment developers and others. Our previous study funded by the Nuffield Foundation (Evolution & Inheritance Project, Study 1, ref. 41491), provided evidence including children's conceptual difficulties with macroevolution – a key concept and critically important in understanding biological science. In the context of discussions about inheritance, some KS2 pupils referred to DNA, though this is not an expectation of the national curriculum and had not been explicitly explored by teachers.

The overall conclusion from Study 1 was that much more attention and support for progression in understanding Evolution and Inheritance, both within KS2 and across Key Stages 2-3 was needed. (This was confirmed by the group of secondary teachers who commented upon 'secondary readiness' of primary pupils, see report, 'Understanding of Evolution and Inheritance at KS1 and KS2: Report on feedback from KS3-KS4 biology teachers' at http://www.nuffieldfoundation.org/pupils-understanding-evolution-inheritance-and-genetics). Three specific areas where curriculum and pedagogy at the KS2-3 transition hold the prospect of novel and useful insights into teaching and learning were the intended foci for the Study 2 research.

Focus i): Macroevolution. The project explored the extent to which encouraging pupils' metacognitive reflection on the meaningfulness to them of a variety of 2-D and 3-D representations of the Tree of Life metaphor might support a 'big picture' or macroscopic view of evolution (described in section 3.1). This focus also supported linking Studies 1 and 2 by informing the construction of a curriculum plan for incorporating a Darwinian perspective on biology in KS1-2 (described in section 3.2).

Focus ii): DNA. The intention was to explore pupils' informal understanding as garnered from entertainment and other broadcast media and to arrive at practical guidance for science teachers on the basis of a better understanding of pupils' informal ideas about DNA, including suggestions for adjustments to the curriculum, (described in section 3.3).

Focus iii): Working scientifically using argumentation. This aspect of the research explored what can be learned about the successes (and ways of building on these) and difficulties (and ways of obviating or finding positive solutions to these) of managing pupils' scientific discourse activities across KS2-3 in the conceptual domains of macroevolution and DNA (described in section 3.4).

2. Project methods

The sample of twelve teachers, teaching across Years 5-9 (aged 9-14 years), was drawn from primary and secondary schools in the North West of the UK (Lancashire and Fylde). This region of the UK was geographically convenient to the researchers and like all other areas of England, included schools that deliver the statutory national curriculum. The sample covered a range of urban and rural catchment areas (see Appendix 5 for sample details) and can be considered as representative of science teaching in general for the purposes of our research.

The regulations of the University of Liverpool's ethics committee along with the guidance offered by ESRC and BPS were observed in all aspects of activity including the collection, recording, reporting, evaluating, disseminating and archiving of data. Written carer or parental consent was collected for children involved in the project. Additionally, prior to observing and audio recording children and adults, the researchers asked for their permission so as to ensure they were comfortable with our presence. Drafts and final versions of materials and reports etc. along with any edited images and audio files were shared with teachers prior to publication. This practice ensured that participants were in agreement with the interpretation and use of the evidence collected (http://www.esrc.ac.uk/ESRCInfoCentre/Images/ESRC_Re_Ethics_Frame_tcm6-11291.pdf)

There were differences in the methods adopted for various aspects of the research.

- To explore effective strategies for approaching the teaching and learning of macroevolution, all teachers introduced all pupils to six different representations of the Tree of Life metaphor (Figures 1-6, page 11). Each teacher worked with all the pupils in their class in an open-ended manner, promoting intra-psychological (within-pupil) reflection coupled with inter-psychological (between-pupil) exchanges of ideas and understandings. The order in which the different representations were introduced was at each participating teacher's discretion. Pupil interviews were conducted by the researchers with a sample of six pupils stratified by gender and overall attainment drawn from each class, attainment being by teacher judgement of science at KS3 and across all subjects at KS2. The 72 interviews, each lasting around 20 minutes, were audio recorded and transcribed in full prior to analysis. (The interview protocol is reproduced as Appendix 1.)

- A structured questionnaire (see Appendix 2) was used to elicit written responses to a set of questions that probed all pupils' awareness of DNA. It was emphasised to pupils that this procedure was not to be regarded as a science test but rather as a means of finding out their existing ideas as gathered from everyday sources. The collection, coding of responses and subsequent analysis of pupils' ideas about DNA involved all available pupils in the project classes (*n*=298), not just the interview sub-sample.

- Teachers arranged class argumentation activities around pupils' beliefs about macroevolution and DNA, some of which sessions the researchers were able to observe. Prior to discussion, pupils explored ideas using the Internet. Teachers' written reflections on the effectiveness of the organisation and process of the science discourse, including evidence of the quality of pupils' arguments, were collected. In response to a request from some teachers for guidance as to the criteria to apply in their reflections on the success of the discussions, some suggestions were offered (see Appendix 3). However, these criteria were not imposed (in order to avoid a further demand on teachers' time) and so were not mandatory. In the event, only one teacher used the full set of criteria to report her reflections on argumentation. Others commented more generally on the argumentation process in their written feedback. In addition, pupils' perceptions of the role of such discussions in promoting their science understanding were collected using rating-scale responses (see Appendix 4). All available pupils (*n*=311) and their teachers (*n*=12) completed this rating scale.

Appendix 6 summarises the different sources of data gathered in Study 2.

3. Key Findings and Linked Outputs

3.1 Macroevolution

Despite teachers' own initial unfamiliarity with cladograms (branching diagrams showing the relationship between species as they have evolved from most recent common ancestors into different species over millions of years), pupils' positive responses led both teachers and pupils to welcome almost unanimously the early introduction of this representational format. A positive impact of cladograms on pupils' understanding of hominid evolution in particular and the process of speciation more generally was confirmed. Almost all those pupils interviewed (94%) suggested that the simplified primate cladogram helped their understanding of evolution, explaining that it supported their appreciation of evolutionary timescale, speciation and extinction. Older pupils mentioned in addition an enhanced appreciation of the significance of the concept of Most Recent Common Ancestor (MRCA) and its relevance to the process of speciation.

Introducing a variety of representations of the Tree of Life metaphor (see Figures 1-6, page 11) served to consolidate the notion of macroevolution by providing pupils with the opportunity to reflect upon and to discuss, using evidence-based exchanges, the affordances or weaknesses of each formulation. For instance, a simple real branch introduced to pupils as a physical metaphor for the Tree of Life was confirmed as a valuable and engaging resource that helped to demonstrate abstract ideas in concrete form throughout the age range of the sample. This concrete 3-D model supported appreciation of common ancestry, extinctions and the branching manner in which species separate.

Figures 1-6 Representations of Macroevolution

Figure 1 One Smart Fish Narrative

Figure 2 Real tree branch

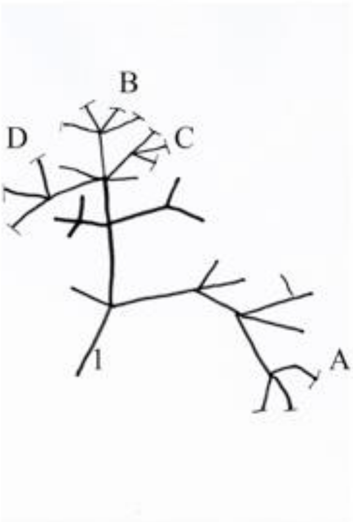

Figure 3 Darwin's Tree of Life Sketch

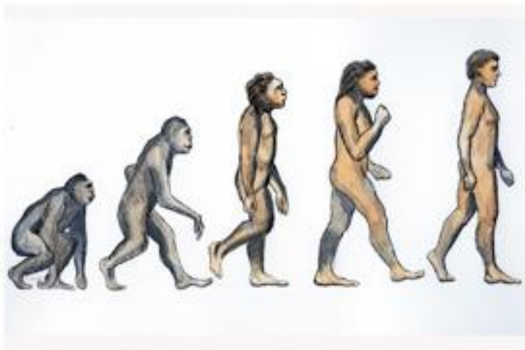

Figure 4 'Ascent of Man' image

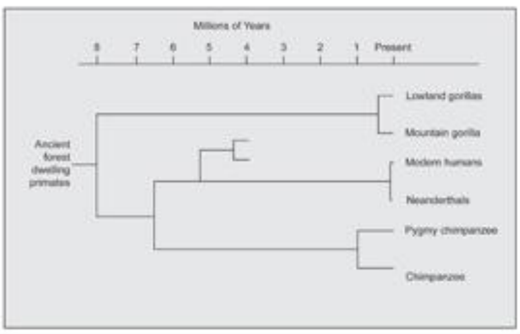

Figure 5 Simplified primate cladogram

Figure 6 Modelling the Tree of Life

Eighty-eight per cent of the interview sample pupils in Years 5-9 recognised the formal but simplified cladogram diagram and the real tree branch as different representational versions of the same Tree of Life metaphor.

Science educators' scepticism about the use of fictional narrative text in scientific contexts tend to centre around concerns about personalising, and perhaps anthropomorphising, the agents, coupled with doubts about pupils' abilities in distinguishing fact from fiction. Teachers found the fictional narrative story of One Smart Fish (Wormell, 2010) a valuable way of introducing pupils to macroevolution. (Younger pupils had the story read to them; older pupils considered the story's suitability for younger children.) Pupils demonstrated that they could distinguish factual and fictional events in the story and almost all the pupils interviewed (86%) believed that fictional narrative supported their understanding of the process of speciation specifically and evolution more generally**.**

The invitation to contribute a chapter drawing on our Nuffield Foundation-funded research to the Springer book edited by Ute Harms of IPN (Kiel) and Michael Reiss (UCL) was opportune. In the submitted chapter, we review both Nuffield Foundation-funded phases of our research into the teaching and learning of evolution across the 5-14 age range. The need we perceived was to link disconnected but relevant curricular fragments into a coherent experience of progression that would reflect the underpinning breadth, depth and interconnectedness of Darwinian evolutionary theory. Five themes were identified to make this ambition manageable: variation, fossils, deep time, selective breeding and macroevolution, exploring what ideas can be developed, at what age and in what order.

Our chapter describes some resulting classroom validated instructional design strategies as an introduction to looking at the primary-secondary transition in more detail. A particular focus is on pupils' access to the key concept of macroevolution, exploring alternative representations of the Tree of Life metaphor as described above. A complementary enquiry was into the practice of science or 'Working Scientifically' as described by the national curriculum. Here the emphasis was on communicative processes and on pupils' epistemic understanding (that is, knowing how their own science knowledge is built up), using science argumentation, during which pupils explored and articulated by reference to evidence what aspects of the various representations helped or hindered their understanding of evolution.

An invitational seminar at IPN, Kiel, in August 2017, provided a platform for the dissemination of Study 2 to about thirty fellow researchers having a profile in evolutionary education research and development internationally.

Output 1: Russell, T. & McGuigan,L. 'Developmental Progression in learning about Evolution in the 5-14 age range in England'. Chapter 4. In Harms, U. and Reiss, M., 'Evolution Education Re-considered – understanding what works'. Springer. (2018).

3.2 Development of a curriculum framework for evolution and inheritance, KS1-2

Study 2 has benefitted from and built on the findings from Study 1; the accumulating evidence has provided the basis for a curricular overview that incorporates a comprehensive Darwinian perspective for biology teaching at KS1-2. Rather than being framed in terms of addressing 'misconceptions', our framework is based on, and assumes the utility to teachers of, developmental learning progressions (DLPs). The implication is that all concepts are approached with a view to pupils' incremental construction of a Darwinian perspective on biological knowledge. One of the products of the collaborative research with teachers, review of the literature and analysis of the practical possibilities for classroom-based progressive activities is an article submitted to the ASE's (Association for Science Education) Primary Science. It is aimed at teachers, teacher educators, advanced teachers and teachers in training. Its unique value is its comprehensive developmental perspective that aims at supporting curricular continuity and progression and a consistent cumulative understanding of the Darwinian perspective. This article uses the same framework that is summarised in Table 2, 'Outline of Developmental Learning Progressions suggested by the research activities', page 14) but populated with a more detailed range of practical examples. While it is not claimed that the DLPs as suggested constitute the only routes towards understanding evolution and inheritance, we have confidence in the classroom validation established by our collaborating teachers, who strongly affirm the developmental perspective advocated.

Opportunity for arguing for a consistent developmental outlook in science education was also presented in the updating of the authors' chapter in the ASE publication, 'ASE Guide to Primary Science': 'Progression', published in January 2018 to coincide with the ASE annual conference. This chapter describes a developmental approach to science education in general and suggests the value for practice of taking account of children's development of thinking and reasoning. This outlook is gaining increased attention: just as society's expectations develop and change, so also education policies and practices are continually revised to keep abreast. In early science education, important shifts in three areas have been driving change. Firstly, there have been changes in expectations for early childhood educational provision, and consequently, a greater awareness of the training needs for practitioners working with younger children. Secondly, recent years have seen increased research and insight into early child development of direct relevance to science education - in particular, a greater awareness of the largely untapped reasoning abilities of young children in selected areas of science. Thirdly, there has been an elaboration of ideas about the 'Nature of Science', with far greater awareness of the importance of communication and children's own mindfulness of what science knowledge is – the epistemic dimension.

We argue that pupils' development of scientific knowledge and knowing about the *how* and *why* of science are intimately connected through domain-specific learning progressions such as those we describe. These suggested DLPs have been informed by and emanate from our research into understanding of evolution and inheritance. This approach can and should inform teaching and learning within and across years and phases of schooling.

Table 2, constructed on the basis of Studies 1 and 2 research activities, provides a succinct overview of the coverage of Output 2.

Output 2: Russell, T. & McGuigan, L. 'Teaching and learning about evolution: A developmental overview'. Article accepted for publication in ASE's Primary Science journal.

Table 2. Outline of Developmental Learning Progressions suggested by the research activities

<table>
<tr><th>Developmental Learning Progression</th><th>Year 1</th><th>Year 2</th><th>Year 3</th><th>Year 4</th><th>Year 5</th><th>Year 6</th></tr>
<tr><td rowspan="2">Variation</td><td colspan="6">Observing, counting & measuring within species differences in plants and animals in different habitats, moving to measuring & recording differences & distributions of e.g. size, shape, colour.</td></tr>
<tr><td>Observe & compare within-species plant & animal differences</td><td>Order, count & measure range of attributes of living things</td><td>Observe & record the shapes of distributions of differences</td><td colspan="2">Measure and plot distributions</td><td>Explore different shapes of normal distributions</td></tr>
<tr><td rowspan="3">Deep Time</td><td colspan="6">Learning the names & magnitude of numbers through tens, hundreds, thousands, millions to billions; construct & appreciate the meaning, need for and use of scales</td></tr>
<tr><td colspan="6">Informal surrogate measures for passage of time (‘sleeps’, birthdays, generations, etc.)
Understanding passage of seasons & structure of calendar time (days, weeks, months, years).
Lifespans & timelines of historical events.</td></tr>
<tr><td colspan="6">Models of evolutionary time using approximation of 4.5 billion years to range of scales: timelines of different scale & sides of paper in ring binder</td></tr>
<tr><td rowspan="2">Fossils</td><td>Observe, handle and name a range of plant & animal fossils</td><td>Extend the range of experience of fossils through fieldwork & museum visits.</td><td>Sequenced drawings back through time of fossil formation</td><td>Modelling reconstructions of animals from fossils</td><td colspan="2" rowspan="2">Biographies - (Darwin, Mary Anning, etc.). Special interests of individuals – e.g. dinosaurs or fieldwork, collections.</td></tr>
<tr><td colspan="4">Model the sedimentation process, fossil formation & links between extinct and living species</td></tr>
<tr><td>Selective Breeding</td><td colspan="2">Cross-generational likeness in animals and plants
Making imaginary pets with focus on their traits</td><td>Histories of domestication of animals, crops & pets.</td><td colspan="2">Investigate breeding for desirable traits: e.g. assistance dogs, designer pets, meaning & process of pedigree breeding.</td><td>Animal & plant breeding. Continuous & discontinuous traits</td></tr>
<tr><td rowspan="3">Macroevolution descent, Most Recent Common Ancestors (MRCAs) & extinctions.</td><td colspan="6">Narrative fiction describing speciation events throughout the age range & beyond, antecedents of appreciating homologies.</td></tr>
<tr><td></td><td colspan="5">Real tree branch as developing metaphor for common descent, speciation, MRCAs & extinctions & analogue for Darwin’s tree of life sketch</td></tr>
<tr><td colspan="4">Construction of posters in the form of collages of illustrations of the history of life on Earth</td><td colspan="2">Simple cladograms introduce quantification of evolutionary change; 3-D models of partial cladograms.</td></tr>
<tr><td colspan="7">*Adaptation – Different habitats & animals’ and plants’ adaptive features; awareness of habitat loss or destruction threatening extinction; conservation possibilities. Food chains and moving towards food webs, interdependence, developing towards an ecological perspective. * Not part of current reported research as this area tends to be well covered in primary schools.</td></tr>
</table>

3.3 Pupils' ideas about DNA

The evidence from our questionnaire enquiry involving 298 pupils in Years 5-9 (see Appendix 2 for questionnaire) suggests that pupils construct informally an awareness of DNA through their exposure to popular media. Although the concept is not included in the KS2 science curriculum for England, half the pupils (54%) in Y5 and about four-fifths (79%) in Y6 demonstrated awareness of DNA in their responses to the conceptual probes. Television, news and film as well as popular music were most frequently cited as their sources of information. They showed awareness of how DNA might be used by police (for forensic identification) and medical professionals (to identify, treat and cure diseases), and by the general public to identify missing or re-discovered family members. Their sources included popular TV programmes, but also direct personal experience.

Macroscopic ideas about the location of DNA being found in e.g. 'hair' and 'skin' etc. were held by about three-quarters (72%) of pupils. The frequency of such ideas decreased with age, whereas microscopic responses describing DNA as being located in cells, increased with age. An awareness of DNA in cells was expressed by less than a tenth (8%) of pupils in Years 5-7, but was mentioned by two-thirds (66%) of Year 8 pupils and almost three-quarters (71%) of Year 9, reflecting exposure to the KS3 biology curriculum.

One tenth (12%) of Year 5 pupils and a fifth (20%) of Year 6 revealed awareness that DNA can cross generations. The proportions expressing this belief gradually increased with age so that by Year 9, almost two-thirds (62%) explicitly confirmed understanding of the transfer of DNA from parents to offspring.

A possible link with experience of the function of computer software was inferred when understanding of DNA's mechanism was expressed as a set of 'instructions'. This formulation was in evidence from just under a tenth of pupils overall, but with an age-related increase in this interpretation. While in years 5 and 6 only one pupil and in year 7, only two pupils framed their understanding in this manner, the proportion rose to a quarter (24%) of Y8 and two thirds (67%) of Year 9 students.

The Human Genome project (2003) has enormous implications for therapeutic intervention as well as other aspects of peoples' lives; it is and will be hugely important in scientific research. Despite its importance, almost all pupils were unfamiliar with this programme of research.

In the context of 'three-parent-babies' (a topic that had received widespread attention in the broadcast media at the time of our research), about a fifth (21%) of respondents suggested that the expression referred to some form of exchange of genetic material between three people. This quality of response tended to increase in line with increasing maturity across the Years 5-9. Genetic exchange was rarely mentioned (4%) at Year 5 but was suggested by all (100%) of the Y9 pupils.

Given some expressed public alarm in the context of genetically modified crops, for example, pupils were asked if they had heard of concerns about DNA research and if they held any concerns themselves. The majority of pupils suggested they had not heard any concerns about DNA, though just over a tenth (14%) suggested they had heard of some apprehensions. Fewer (8%), claimed to hold concerns themselves.

Having concerns about DNA research was very much age related. While two-thirds (62%) of Y9 pupils had concerns, there were few such expressions from Y7 (5%) and Y8 (7%) pupils and none from primary phase pupils.

Pupils' views on the location of DNA, its function and more specifically, its role in human reproduction, were recorded and age-related trends identified. It was confirmed that some knowledge of the term 'DNA' and superficial aspects of technical applications had been gained. However, there was little awareness of the underlying science prior to formal teaching in secondary school.

Currently, curriculum changes in England in science, but also in Computing and in PSHE education, can be interpreted as converging in an important manner relevant to learning about inheritance. Inheritance introduced to the primary curriculum finds pupils expressing some notions of traits crossing generations, but little awareness of mechanisms. Yet there is fairly widespread use of the term 'DNA' amongst primary pupils and some understanding of links to individual characteristics. The PSHE curriculum has been under recent review and a joint ASE-PSHE recommendation addresses the manner in which Relationship and Sex Education (RSE) might be approached. For example, appropriate vocabulary to use to teach sexual reproduction in plants and animals, including 'sperm' and 'egg'.

In parallel developments, even at KS1 in the Computing curriculum, pupils should be taught to understand that 'programs execute by following precise and unambiguous instructions'. Together, significant educational innovations of the Computing and PHSE curricula have the potential to reinforce both the metaphor and the mechanism of DNA's role in inheritance.

The late primary to early secondary science curriculum in England currently does not support the basis for beginning to comprehend DNA's role. Some steps are missing to arrive at a DLP offering continuity in pupils' understanding. Yet such an approach, one that favours defining a progression from late primary to early secondary education, is feasible. Around this primary to secondary transition, our research suggests, is an appropriate time to introduce the currently missing core concepts of the *cell*, *controlling nucleus* and *cell division*.

Rather than view informal ideas as misconceptions to be eradicated, erroneous though they often are, it is argued that educational interventions are better thought of within the framework of DLPs. Within such an overarching perspective, the roles of metaphors, simulations, narrative and concrete modelling as strategies for supporting the development of understanding are considered. This broad strategy addresses approximate, fragmentary and disconnected ideas in pursuit of continuity and progression in learning. We draw the conclusion that an approach that favours defining a DLP relating to inheritance from late primary to early secondary education is feasible and logically compelling.

A Primary Science article will be aimed more specifically at primary teachers. Our research has confirmed that while KS2 pupils use some notions of kinship similarities, little awareness of the mechanism of inheritance was in evidence. The intention is to offer a curriculum analysis that results in building on existing awareness in the direction of continuity and progression in older primary pupils' appreciation of the role of DNA in inheritance. A full analysis of all the data pertaining to pupils' ideas about DNA has helped us to identify the direction and content of this article.

Output 3: Paper for submission to the ASE's Primary Science journal. 'DNA, Computing and Relationships & sex education at KS2'

3.4 Argumentation

Argumentation practices (as these are currently understood in science education research) were not found to be part of our project teachers' current habitual practices and were not embedded in schools' approaches to working scientifically. In the course of the project, teachers were encouraged to develop strategies designed to encourage pupils' active identification, evaluation and use of information as evidence to support claims. The feedback from pupils confirmed the success of these strategies, with almost three-quarters (70%) of pupils agreeing that their peers used evidence to back up their claims during their discussions.

A novel aspect of the project was the focus on pupils' cognitive and affective responses to the opportunity to engage in argumentation. Following the encouragement to explore argumentation sessions within the framework of our research, almost all pupils (95%) and their teachers agreed that they found discussion helpful to their science understanding. Some illustrative responses from pupils (tagged by gender and Year group in the examples that follow) suggest they modified their ideas during these discussions.

> *I think discussion with my classmates was probably the best helping me to understand the evolution. I changed some of my opinions because I thought that some of my classmates' opinions were actually right.* (Y7M)
>
> *The most helpful was the debate. We heard other people's ideas and I learned from their arguments and evidence. I really thought it was helpful.* (Y7F)
>
> *The thing that helped me understand it was having a discussion about it and, like most of understanding it from listening to other peoples' points and thinking about what it could be.* (Y8M)

The results of the research with pupils in the range years 5-9 suggest an overwhelmingly positive response to argumentation by pupils and their teachers. Nonetheless, about a fifth (21%) expressed some apprehension in relation to expressing their ideas in a classroom context. The requirements of this minority group need to be taken seriously. Our previous research with a younger age range than reported on here points to the priority that must be given to encouraging the expression of ideas from the point of entry to school. Urgent attention to this need is integral to educational socialisation. It would be helpful to adopt a long view of the developmental process of students' engagement in dialogic practices. There is evidence from project teachers' views of the impact of involvement in the project on their practice that the argumentation techniques developed in the course of the research were rapidly generalised to other curriculum areas. They occasionally assumed the centre piece of cross-school events, such as SALAD (Speaking and Listening Days) days, in which the major focus was the encouragement of pupils' participation in speaking and listening.

The need we perceived in the context of teachers' efforts to promote argumentation was for some form of resource that would faciltate the development of teachers' management of classroom discussion processes. Previous research experience had confirmed pupils' strong attraction to engage when exposed to their peers' recorded ideas. The audio recordings collected in the course of pupil interviews were recognised as a valuable re-usable classroom resource: a set of pupils' claims that might be made freely available to teachers. The audio clips are intended to be used practically by teachers and pupils as starting points for argumentation sessions. (Permissions from parents were gathered and identifying names are removed so that anonymity is safeguarded.)

One of the difficulties of managing classroom argumentation is the maintenance of a focus on particular expressed idea-claims when discourse is so fluid and ephemeral. The Teachers' Notes accompanying the audio clips emphasise the identification of the specific claims made in any particular utterance. The recordings enable an argument to be re-visited as many times as necessary, by teachers or pupils, and as such, offer a rehearsal experience for both parties. It is anticipated that the website resource will encourage pupils to attend closely to each other's ideas, help to overcome any reticence on the part of some pupils and facilitate the development of argumentation practices in schools as routine. An important aspect of argumentation is pupils' expression of a diverse range of claims to which other pupils can respond. We anticipate that pupils across the age range will find the diversity of claims expressed engaging, both more and less enlightened than their own currently held beliefs, and that this will, in turn, encourage wider participation.

Output 4: A website resource for teachers and pupils constructed around a selection of audio clips of pupils' ideas drawn from the interview record, together with teacher guidance notes for classroom use across Y5-9**:** www.ideasaboutevolution.com The site is publicised in hard and digital copy publications including those of the Association for Science Education and the European Science Education Research Association. The Internet is anticipated to offer a wide range of possibilities for raising awareness of this free resource for teachers.

Increasingly, science education assumes an important role for the epistemic dimension in which classroom discussion and argumentation play a vital role. As described above, all pupils had opportunity to exchange their ideas with their peers through teacher-managed classroom discussion and argumentation processes, allowing the researchers to ascertain pupils' affective and cognitive perceptions of such exchanges, a relatively neglected area of enquiry. Although research into the instrumental value of argumentation assumes students' active participation in their own learning, there has been a dearth of curiosity about the pupils' own reflections on the process. *A priori*, several contributory factors might be identified as influencing willingness to participate: (i) Individual factors including pupil personality and disposition; (ii) school ethos and educational induction over years of schooling into 'communication rules' and (iii) classroom micro-climate (e.g. teaching style, curriculum and exam pressure, as well as peer social behaviour). The project collected evidence of pupils' affective and cognitive responses to argumentation. We have analysed the complete data set (*n*=311) and results are summarised in this report (section 3.4) and in the Springer chapter.

Output 5: The role of class discussion in learning about evolution and inheritance at KS2-3. Paper submitted to ESERA (European Science Education Research Association), Dublin 2017 (not accepted for ESERA, but the data are introduced to the Harms & Reiss chapter.) 'Students' perspectives on science discussion and argumentation'. A modified paper to the ASE's School Science Review explores pupils' own views of the contribution of class discussion to their learning.

Output 6: Helping children to express their ideas and move towards justifying them with evidence : A developmental perspective. Association of Science Education (ASE) International no2, pp6-10, 2018.

Over the past decade or so, science education researchers' views of science have been extended to include an emphasis on social and epistemic processes that may be realised in science discourse practices. We argue that this contemporary understanding of what constitutes science education should be acknowledged in the form of new possibilities for early years practitioners to make significant contributions to an authentic science experience for young children. The epistemic and communicative aspects of science that are increasingly recognised as essential can be introduced by all early years practitioners as a form of discussion that can permeate all settings. Using quantitative and qualitative evidence derived from our linked projects we argue that practitioners are well placed to nurture early scientific reasoning behaviours that resonate with contemporary views of science. Although focusing on the needs of a younger age group than is the focus for Study 2, we draw on some of the evidence from Study 2 along with Study 1 to argue for an epistemic approach to science in the early years, coupled with practical guidance.

Output 7: 'Reflections on guidance to orientate untrained practitioners towards authentic science for children in the early years'. Paper presented to ESERA (European Science Education Research Association), Dublin, August 2017. The published extended paper is McGuigan, L. & Russell, T. (2018). Reflections on guidance to orientate untrained practitioners towards authentic science for children in the early years. In Finlayson, O.E., McLoughlin, E., Erduran, S., & Childs, P. (Eds.), Electronic Proceedings of the ESERA 2017 Conference. Research, Practice and Collaboration in Science Education, Part 15: Strand 15 co-eds. Bodil Sundberg & Maria Kallery (pp. 2034 - 2045). Dublin, Ireland: Dublin City University. ISBN 978-1-873769-84-3

Output 8: McGuigan, L. & Russell, T. (2018). Reflections on guidance to orientate untrained practitioners towards authentic science for children in the early years. Journal of Emergent Science 15. pp28-37.

4. Evaluation

An evaluation of the impact of Study 2 teachers' project involvement on their practices was carried out in July 2017, immediately following completion of their participation. All twelve teachers responded to semi-structured interviews. Although the project did not undertake professional development activity *per se*, the evaluation invited comments on any project impacts on their own practice, on pupils and on their schools.

This brief Study 2 evaluation of impacts found evidence that teachers viewed the project as having helped to increase their awareness of some of the ideas pupils held in relation to macroevolution and DNA, contributed to teachers' pedagogical knowledge and helped develop teachers' confidence and science content knowledge associated with macroevolution and DNA. Teachers reported that pupils engaged with the targetted conceptual domains and produced some pleasing and surprising learning outcomes in response to what many initially believed were challenging activities. Some of the teachers described how the argumentation strategies had been disseminated and incorporated into practice across their school. While we acknowledge that it takes time for new strategies to become embedded into practice, feedback on this occasion suggested some immediate and positive impacts.

Output 9: Research to Support Understanding of Evolution and Inheritance in the National Curriculum at KS2 and KS3: Teachers' views of the impact of involvement in the project on their practice. This evaluation of teachers' views of impacts of Study 2 is available on the Nuffield Foundation website and on the authors' ResearchGate profile pages.

Output 10: Research to Support Understanding of Evolution and Inheritance in the National Curriculum at KS1 and KS2: Evaluation of impact. This evaluation of teachers' views of impacts of Study 1 is available on the Nuffield Foundation website and on the authors' ResearchGate profile pages.
http://www.nuffieldfoundation.org/pupils-understanding-evolution-inheritance-and-genetics

Output 11: **'**Ideas about Evolution: a website resource to support the development of pupils' argumentation**.'** An article prepared for ASE's 'Primary Science' and 'Education in Science' journals (2018) to disseminate the website www.ideasaboutevolution.com to Primary and Secondary science teachers.

5. Implications and Recommendations for Policy and Practice

The Study 1 and Study 2 projects argue strongly for a developmental perspective on pupils' understanding of evolution and inheritance. While it is not claimed that the developmental learning progressions (DLPs) suggested constitute the *only* routes towards understanding evolution and inheritance, we argue that the claim for initial classroom validation of this perspective has been established. Our argument is that DLPs do not sit waiting to be discovered by researchers: they must be actively and imaginatively constructed by considering developmental capabilities, the logic of the subject matter and optimal representational formats (or models) for encapsulating knowledge that can be invented by educators. Evidence from Study 2 has enabled us to add to the developmental picture across KS1-2 and into KS3. One major outcome is that we have attended to the practical implementation of a curricular map for the introduction of a Darwinian perspective on evolution and inheritance. This framework (see Table 2) sets out for practical purposes the way in which the curriculum might be sequenced to support progression across Key Stages 1 and 2 and transition to KS3.

Evidence from Study 2 confirms the validity of the early introduction of macroevolution to pupils in Y5-6. Speciation within macroevolution and the idea of common descent as a precursor to appreciating the idea of MCRAs was found to be accessible to older primary pupils. The use of a range of representations of the Tree of Life is advocated by the research, with pupils encouraged to use a metacognitive process of representational redescription to translate between formats. Translation between representations, it is argued, serves to consolidate understanding.

Pupils' awareness of DNA and its technical application in forensics, in identifying disease and in establishing family relationships was confirmed, even amongst some of the younger pupils in Years 5 and 6. Earlier introduction of the concept of cell is recommended along with strategies that encourage pupils to think of DNA within the cell nucleus as a set of instructions (akin to their learning about computer software code) that transfers from one generation to the next. Significant educational innovations of the Computing curriculum in the form of an emphasis on programming, coupled with proposed changes to the PSHE and relationship education curriculum have the potential to reinforce both the metaphor and the mechanism of DNA's role in inheritance.

An important aspect of argumentation is pupils' expression of a diverse range of ideas as claims to which other pupils can respond. The project's accumulated examples of pupils' claims across Y5-9 recorded in audio format provide a valuable starting point for argumentation sessions. The website www.ideasaboutevolution.com including a selection of audio files makes this resource widely available.

6. Project dissemination outputs

In summary, the following outputs fulfil our dissemination commitments:

Output 1: Russell,T. & McGuigan, L. (2018) 'Developmental Progression in learning about Evolution in the 5-14 age range in England'. Chapter 4, In Harms, U. and Reiss, M., 'Evolution Education Re-considered – understanding what works'. Springer. Awaiting final copy, page numbers and ISBN information

Output 2: Russell, T. & McGuigan, L. (2018) 'Teaching and learning about evolution: A developmental overview'. Accepted for publication in ASE's Primary Science journal.

Output 3: Paper for submission to the ASE's Primary Science journal, provisional title, 'DNA, Computing and Relationships & sex education at KS2'

Output 4: Russell, T. & McGuigan, L. (2018). A published resource for teachers comprising a selection of audio clips of pupils' claims drawn from the interview record together with teacher guidance notes, available on line for classroom use across Y5-9**.** Web site: www.ideasaboutevolution.com

Output 5: 'Students' perspectives on science discussion and argumentation'. A paper to the ASE's School Science Review explores pupils' own views of the contribution of class discussion to their learning.

Output 6: McGuigan, L & Russell, T. (2018) 'Helping children to express their ideas and move towards justifying them with evidence : A developmental perspective'. Association for Science Education (ASE) International no2, pp6-10, 2018.

Output 7: McGuigan, L. & Russell, T. **(**2018) Reflections on guidance to orientate untrained practitioners towards authentic science for children in the early years. In Finlayson, O.E., McLoughlin, E., Erduran, S., & Childs, P. (Eds.), Electronic Proceedings of the ESERA 2017 Conference. Research, Practice and Collaboration in Science Education, Part 15: Strand 15 co-eds. Bodil Sundberg & Maria Kallery (pp. 2034 - 2045). Dublin, Ireland: Dublin City University. ISBN 978-1-873769-84-3

Output 8: McGuigan, L. & Russell, T. (2018). Reflections on guidance to orientate untrained practitioners towards authentic science for children in the early years. Journal of Emergent Science. 15. pp28-37.
Output 9: 'Research to Support Understanding of Evolution and Inheritance in the National Curriculum at KS2 and KS3: Teachers' views of the impact of involvement in the project on their practice'. http://www.nuffieldfoundation.org/pupils-understanding-evolution-inheritance-and-genetics
Output 10: Research to Support Understanding of Evolution and Inheritance in the National Curriculum at KS1 and KS2: Evaluation of impact. http://www.nuffieldfoundation.org/pupils-understanding-evolution-inheritance-and-genetics
Output 11: 'Ideas about Evolution: a website resource to support the development of pupils' argumentation.' An article prepared for ASE's 'Primary Science' and 'Education in Science' journals to disseminate the website ideasaboutevolution.com to Primary and Secondary science teachers. Accepted for publication.

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Appendix 1. Macroevolution Interview Protocol

Evolution Interview

1. Personal Research

Did you do try to find something out about evolution? How did you do it?
(Invite description.)

Let's look at your definition of **what evolution is**? (Discuss written definition & any change & any evidence.)

Let's look at your definition of **how evolution happens**? (Discuss written definition, any change and any evidence.)

2. One Smart Fish

With written Fact-Fiction response to hand: Invite elaboration of written comments, probing science knowledge.

	Yes	No	Extent of knowledge
Reference to evolution land to sea?			
Unsolicited reference to coelacanth?			
Unsolicited ref. to Tiktaalik?			

Do you think it's helpful to use fictional stories to learn about science? Elaborate.

Any drawbacks?

3. Cladogram

Do you see any similarity between the cladogram and: -

3i Darwin's sketch?

Interviewer/Date Date 1 Date 2 Date 3 1

Name School Year M: a b c F: a b c

3ii The real branch?

3iii The image of human evolution?

How does the cladogram add to your understanding of evolution?

Is there anything about the cladogram you would find difficult to explain, or that you're confused about?

4. Summary Review Looking back over the various ways of showing evolution, which aspects did you find helpful? And which aspects caused you difficulties in understanding?

	Helpful aspects	Caused difficulty in understanding
One Smart Fish Story		
Darwin's tree of life sketch		
Real tree branch		
Human evolution Image.		
Cladogram		
Modelling in 3-D		

Interviewer/Date Date 1 Date 2 Date 3 2

Name School Year M: a b c F: a b c

4. Review of class discussion as 'Working Scientifically'

Did you take part in a whole class discussion?

How did you feel about expressing your own ideas in front of the class?

How did you find the exchange of ideas during whole class discussions?					
AGREEMENT?	I always agreed	Mostly agreed	Couldn't decide if I agreed with others or not	Mostly disagreed	Always disagreed
GIVING REASONS?	They always gave reasons	Mostly gave reasons	Not sure if they gave reasons	Mostly did not give reasons	Never gave reasons
USING EVIDENCE TO BACK UP IDEAS?	They always used evidence	Sometimes used evidence	Not sure if they used evidence	Mostly did not use evidence	They never used evidence
OTHERS' IDEAS INTERESTING?	Extremely interesting	Slightly interesting	Neither interesting nor uninteresting	Not very interesting	Not in the least interesting
OTHERS' IDEAS SURPRISING?	Extremely surprising	Slightly surprising	Neither surprising nor unsurprising	Not very surprising	Not in the least surprising
OTHERS' IDEAS SCIENTIFICALLY ACCURATE?	Extremely accurate	Slightly accurate	Neither accurate nor inaccurate	Slightly inaccurate	Very inaccurate
HELPFUL TO YOUR OWN UNDERSTANDING OF EVOLUTION?	Extremely helpful	Slightly helpful	Neither helpful not unhelpful	Slightly unhelpful	Extremely unhelpful

Do you think a class discussion where you debate or argue with evidence is a good way to learn science?
(Invite recollection of useful exchanges.)

Can you think of any ways in which your ideas have developed or changed as the result of all the activities about evolution?

Of all the activities, what did you find particularly useful in helping your understanding of evolution? Reason with evidence.

Interviewer/Date Date 1 Date 2 Date 3 3

Appendix 2. DNA Administration and Questions: 'Ideas about DNA'

The exploration of pupils' ideas about DNA: notes for teachers' administration.

The four steps we would like followed are:

1. **DNA questions via PPT.** Brief teacher introduction to administering the DNA questions via PPT using interactive whiteboard (IWB). This will be a standalone activity.
2. **Pupils' personal research**. Some time after responding to the DNA questions – the time lapse is not important - pupils can be invited to carry out some personal research, perhaps as homework. As an orientation to setting this 'finding out' task, the class discussion question can be introduced. Step 3, class discussion, should follow on fairly closely, within a few days.
3. **Argumentation/Class discussion** centred on the agreed class discussion question, with pupils referring to the evidence they have collected in their research.
4. **Rating scale.** To round off the DNA activities, pupils complete the rating scale, administered via PPT.

   1. *DNA questions via PPT.* Our intention is to capture pupils' 'naïve' or 'untutored' ideas, prior to any teaching or personal research, using the set of PPT questions. This should proceed after only a very brief teacher introduction, e.g. (in your own style and words): *'Some of you have mentioned DNA when we have talked about evolution. You may have heard DNA discussed on TV, radio, and newspapers or in conversations. Before doing any further research or finding out, I would like to get an idea of what ideas you have, if any, and what you know about DNA.'* Emphasise that this is not a test of what they have been taught, but what they have picked up informally. *'We are not looking for 'right answers' because this is not a science test. It is about your everyday knowledge, so we would like you to write about your own ideas.'* Pupils write their responses on paper with name, form and school and carefully numbered responses corresponding to the IWB presentation.
   2. Some time later – the time lapse between steps 1 and 2 is not important so could be a few days or a few weeks - pupils are invited to discuss their knowledge and understanding of DNA in pairs and to carry out some online research. This could be introduced as a homework topic. To give some structure to their finding out, the class discussion question could be introduced. *'The discovery of DNA is one of the most important and life changing scientific breakthroughs in the history of science'. What evidence would you suggest to support or argue against this statement?* Tell them that later, they will have an opportunity to discuss this in class.
   3. Introduce the class discussion or argumentation session. There may be different points of view in support of the statement that could be contested. Or some pupils may wish to argue against the statement. Teachers are asked to record their observations about the quality of pupils' argumentation. (See Guidelines on Discussion/Argumentation Criteria.)
   4. Some time after the class discussion session (the time lapse is not critical, but it may be convenient to complete this and wind up the topic right away), all pupils in the class can be invited to respond to the Class Discussion Rating Scale. This can be presented via the IWB, with each pupil recording their decisions in the form of numbers 1-5, using pencil and paper.

Name:	Year:	School:	Teacher:

YOUR IDEAS ABOUT DNA

1.Describe some of the ways in which you have heard about DNA – as many different situations as you can recall.

DNA AND PEOPLE

2a. Where in the human body do you think DNA is found?
2b. What does DNA do?
2c. What has DNA got to do with how we look?
2d. How is DNA passed onto offspring?
2e. What could a scientist tell you about yourself from an analysis of your DNA?

HOW DO SOME PEOPLE USE DNA IN THEIR WORK?

3a. How do doctors & medical people use DNA?
3b. How do the police use DNA?
3c. How do biologists who study evolution (palaeontologists) use DNA?
3d. Some films like Jurassic Park suggest it is possible to recreate extinct animals by finding and using their DNA. What do you think?

HUMAN GENOME PROJECT

4a. In 2003, the completion of the Human Genome Project was announced. Have you heard of this project? Write what you know about it.
4b. How might the Human Genome project be useful to individuals and society?

5a. 'Three-parent babies' have been in the news. What do you understand about 'three-parent' babies?
5b. How are three-parent babies produced?
5c. Why should parents want to have three-parent babies?

CONCERNS ABOUT DNA RESEARCH?

6a. Have you heard any concerns about DNA?
6b. Do you have any concerns or views about DNA research?

Appendix 3. Guidelines for Teachers on Discussion/Argumentation Criteria

The criteria below are to help you to structure your observational notes on how you feel the class discussion/argumentation session went.

Speaking
How clearly presented are pupils' presentation of their ideas or 'claims'
Is evidence used to support the claims made?
Is there a good relevant match between claims and supporting evidence?
Is there a calm, rational and logical style adopted in presentations?

Listening
Do all class members listen to ideas attentively, with engagement?
Is respect show towards presenters and their claims?
Are there any requests for clarification of the claims that have been presented?

Making counter-claims
Are pupils able to keep track of the claims being made?
Are disagreements expressed as counter-claims that are relevant to the initial claim?
Are counter claims supported with evidence?
Are counter-claims treated with respect and seriousness?

Pupils' Engagement
Were pupils engaged with and attentive to the discussion?
Was your impression that this is the kind of activity they would like to repeat?

Teacher management
How did you organise the argumentation session and introduce the question to make it age appropriate?
How would you sum up your attitude to class discussion/argumentation sessions in science lessons?
Has the procedure as we have described it in this project added anything novel to your teaching? (Please be as specific as you can.)
Any difficulties?

Appendix 4. Class Discussion and Science Understanding Rating Scale

Pupil rating scale

How did you find the exchange of ideas during whole class discussions?					
	5	**4**	**3**	**2**	**1**
A. Did you agree with the ideas expressed by other children?	I always agreed	Mostly agreed	Couldn't decide if I agreed with others or not	Mostly disagreed	Always disagreed
B. Did people give reasons for their ideas?	They always gave reasons	Mostly gave reasons	Not sure if they gave reasons	Mostly did not give reasons	Never gave reasons
C. Did the others give evidence to back up their ideas?	They always used evidence	Sometimes used evidence	Not sure if they used evidence	Mostly did not use evidence	They never used evidence
D. Did you find others' ideas interesting?	Extremely interesting	Slightly interesting	Neither interesting nor uninteresting	Not very interesting	Not in the least interesting
E. Did you find others' ideas surprising?	Extremely surprising	Slightly surprising	Neither surprising nor unsurprising	Not very surprising	Not in the least surprising
F. Did you think that others' ideas were scientifically accurate?	Extremely accurate	Slightly accurate	Neither accurate nor inaccurate	Slightly inaccurate	Very inaccurate
G. Did you find discussion was helpful to your own understanding?	Extremely helpful	Slightly helpful	Neither helpful nor unhelpful	Slightly unhelpful	Extremely unhelpful

Teacher rating scale

How did you find the exchange of ideas during whole class discussions/argumentation?					
	5	**4**	**3**	**2**	**1**
A. Did pupils agree with the ideas expressed by others?	They always agreed	Mostly agreed	They couldn't decide if they agreed with others or not	Mostly disagreed	Always disagreed
B. Did people give reasons for their ideas?	They always gave reasons	Mostly gave reasons	Not sure if they gave reasons	Mostly did not give reasons	Never gave reasons
C. Did the pupils give evidence to back up their ideas?	They always used evidence	Sometimes used evidence	Not sure if they used evidence	Mostly did not use evidence	They never used evidence
D. Did you find pupils' ideas interesting?	Extremely interesting	Slightly interesting	Neither interesting nor uninteresting	Not very interesting	Not in the least interesting
E. Did you find pupils'' ideas surprising?	Extremely surprising	Slightly surprising	Neither surprising nor unsurprising	Not very surprising	Not in the least surprising
F. Did you think that pupils' ideas were scientifically accurate?	Extremely accurate	Slightly accurate	Neither accurate nor inaccurate	Slightly inaccurate	Very inaccurate
G. Did you find discussion was helpful to pupils' understanding?	Extremely helpful	Slightly helpful	Neither helpful nor unhelpful	Slightly unhelpful	Extremely unhelpful

Appendix 5. Description of the Sample.

Number of teachers participating in the project

	Y5	Y6	Y7	Y8	Y9	Total
Number of classes	2	3	3	3	1	12
Number of teachers	2	3	3	3	1	12

Number of pupils involved in the project

	Y5	Y6	Y7	Y8	Y9	Total
Interview (subsample)	12	18	18	18	6	72
Written ideas about DNA (all)	41	76	77	83	21	298*
Rating scales (all)	40	63	80	83	45	311*
Classroom activities (all)	41	76	80	83	45	325*

*Data were collected at different times and the presence of all pupils on all occasions could not be assured.

Appendix 6. Overview of Study 2's Sources of Data

Source	**Number**	**Study focus**	**Nature of evidence**	**Mode**
Pupil interviews	72	Macroevolution Argumentation	Quantitative data Illustrative exemplification	Written Audio
Pupil rating scales	311	Argumentation	Quantitative data	Written
Pupils' written ideas about DNA	298	DNA	Quantitative data Illustrative exemplification	Written
Teachers' rating scales	12	Argumentation	Quantitative data	Written
Teachers' writing	24	Macroevolution DNA Argumentation	Illustrative exemplification	Written
Researcher classroom visit notes	48	Macroevolution DNA Argumentation	Illustrative exemplification	Written Photos Audio
Project Meeting notes	2	Macroevolution DNA Argumentation	Illustrative exemplification	Written
Teacher evaluation questionnaire	12	Project Evaluation	Quantitative data Illustrative exemplification	Written