Understanding Evolution and Inheritance at KS1 and KS2: Final Report

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This Final Report is one aspect of a project designed to develop practical guidance for teaching Evolution and Inheritance at KS1 and KS2. Some findings are presented in a series of articles in the Association for Science Education's journal, *Primary Science*. In addition, the authors have produced a project summary, a review of literature and resources, a report on feedback from KS3-KS4 biology teachers and formative assessment probes for classroom use. All of these are available at www.nuffieldfoundation.org/primary-pupils-understanding-evolution-and-inheritance

Executive Summary

Project Aims

The project reported here was a direct response to the new national curriculum for science scheduled to be introduced to Years 1, 3, 4 and 5 from September 2014 and to Years 2 and 6 from September 2015. The project's plan was to conduct research that would inform and support all stakeholders' understanding of the implications of one particular innovation in that policy initiative, namely, the introduction of new subject matter in the form of Evolution and Inheritance. The overriding aim was that project findings would be used to inform teachers' practices and in turn, facilitate and enhance pupils' learning outcomes.

A paramount concern was to identify the prospects for cumulative progression in teaching, learning and pupils' understanding in the foundational concepts relating to Evolution and Inheritance. Specific objectives were to work collaboratively with teachers to:

- identify learners' difficulties and collect evidence to inform optimal learning and teaching sequences;
- develop tailored interventions via formative assessment guidance for practitioners;
- construct descriptions of how understanding and misunderstanding in the domain of Evolution and Inheritance typically develop.

Project Activities

Terry Russell and Linda McGuigan of the University of Liverpool's Centre for Lifelong Learning (and formerly of the Centre for Research in Primary Science and Technology) managed the project. The work used a Design Based Research approach, collaborating intensively with teachers in a relatively small-scale qualitative study over about 18 months.

Twelve teachers across KS1 and 2 in the Northwest comprised the core research group. These teachers were joined by a small number of other more widespread teachers via on-line participation. The issue of 'secondary readiness' was explored using a supplementary questionnaire survey of eleven KS3-4 teachers of biology.

Notwithstanding the relative small numbers involved in this work, the approach was deemed fit for purpose in outlining important strategic approaches to teaching and learning in the focal area and ways of addressing some shortcomings in mapping continuity in pupils' curricular experience across the age range 5-14.

Project Outputs

The specific products generated by the project were

- a bibliography of relevant literature and resources comprising about 250 references to research articles and books as well as museum and other on-line sites, annotated to amplify particularly relevant issues. References deemed particularly useful to the authors in the conduct of this currently reported research were also indicated;
- a set of formative assessment procedures for practical classroom application as well as to enable the replication of some of the conceptual elicitation strategies adopted in the course of the research;
- a report derived from a brief questionnaire enquiry involving eleven KS3-4 biology teachers on the implications of the research activities and outcomes for pupils' transition between primary and secondary education and their consequent 'secondary readiness';

- an overall summary of activities and outcomes (in the form of this report), including a description of the research strategy that was adopted (using design based research and on-line support) as well as an important summary of conceptual trajectories in the development of pupils' understanding, as suggested by the empirical research.

As the project progressed, a series of articles was submitted to and accepted for publication by the Association for Science Education's 'Primary Science'.

Outline of outcomes

The foundational role of the theory of evolution in biology education was confirmed as so broad and pervasive in its implications as to require the identification of sub-domains that would assist manageability. The logic of the subject matter, the psycho-logic of pupils' developing understanding, reference to prior and current research and the particular requirements of the curriculum led to the decision to divide the subject matter into five sub-domains:

- **Variation**: within-species variation being the pre-requisite for selection and speciation over time and as posing a challenge to 'essentialist' beliefs (in which all members of a species are assumed to be fundamentally identical, save for inconsequential differences);
- **Fossils**: the direct source of evidence for evolution, needing to be understood and interpreted as such both in the process of their formation and the information that can be interpreted from them of change over time;
- **Deep time**: the unfamiliar immensity of scale needing to be appreciated in contrast to the scale of human lifespan experience;
- **Selective breeding** as a more accessible and controlled analogue for natural selection advocated as the entry point for consideration of Inheritance;
- **Macro-evolution**, appreciated by reference to the Tree of Life metaphor of evolution as an overarching and accessible visual scaffold that incidentally combats linear and progressive assumptions about the process of evolution.

These sub-domains were (and need to be) treated as closely inter-dependent in nature. In addition, the National Curriculum requirement for all conceptual understanding to be accessed through science processes was addressed through:

- **'Working Scientifically'**, which was particularly important to teachers' practices in the research, the more so in that possibilities for children's own empirical investigations of Evolution and Inheritance are necessarily limited by the nature of the subject matter. The encouragement of children's expression of ideas with the support of evidence was encouraged, leading towards the process of argumentation in which others' ideas were attended to and where deemed necessary, challenged with alternative evidence-based perspectives. This was a particularly novel and challenging area for teachers.

General comments on outcomes

- The interest of children in dinosaurs and fossils had been noted prior to the research proposal, even amongst learners in the Early Years Foundation Stage. The motivation towards ideas associated with Evolution and Inheritance throughout the primary phase proved to be extremely high.
- The National Curriculum as currently framed leaves considerable scope for implementing learning sequences in a manner that would promote continuity and progression more effectively, both within KS1-2 and in the transition to KS3.
- The research identified key elements of foundational understanding and the capabilities of the younger children in the sample in accessing and appreciating aspects of the five themes was striking.
- Children across the age range demonstrated capabilities in presenting and justify their ideas with teacher support. Supporting Working Scientifically and the introduction of

argumentation were perhaps the most challenging aspect of project activities for teachers

- Charles Darwin’s Tree of Life metaphor proved to be a particularly useful scaffolding representation in supporting children’s macroscopic appreciation of the process of evolutionary change. The use of actual branches and children’s own 3-D constructions served to combat linear notions of the evolutionary process. Narrative fiction also introduced some difficult ideas in accessible form. Children took in their stride iterations between non-fiction and fictional sources of information.
- The introduction of cladograms in semi-quantitative form proved a successful component of a multimodal representational approach to children’s understanding of evolution. This proved to be a viable strategy for children towards the upper end of the primary phase, age 10-11 years. The introduction of cladograms by the researchers was innovative and cautious, but KS3-4 teachers were surprisingly positive, given the more orthodox introduction of these diagrams at KS4.
- Productive links were established in primary classrooms between science and mathematics; these links were achieved more readily than was the case in the secondary phase.
- Recent and current biological research including the description of the human genome, genetic modification of crops, cloning of animals, DNA profiling for forensic purposes together with the burgeoning field of epigenetics research is widening the gap between school science and its real world impact. Some children spontaneously referred to DNA in the context of selective breeding, not surprisingly given the coverage in broadcast media. There is a strong case for exploring primary children’s understanding of these topics. References to DNA will be come increasingly significant in everyone’s everyday life. There is justification for research aimed at ascertaining current understanding, both in the public understanding of science and amongst primary pupils. Such research could inform a judicious introduction of strategies to support that understanding.

Section 1 Introduction

1.1 Project Aims

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 KS1-2: teachers, children, policymakers, assessment developers and others. The new curriculum was to be introduced to Years 1,3,4 & 5 from September 2014 and to Years 2 & 6 from September 2015.

The researchers worked collaboratively with teachers to:

- identify learners' difficulties and collect evidence to inform optimal learning and teaching sequences;
- develop tailored intervention via formative assessment guidance for practitioners;
- construct descriptions of how understanding and misunderstanding in the domain of Evolution and Inheritance typically develop.

The intention is that project findings will be used to inform teachers' practices that will in turn facilitate learning outcomes.

1.2 Background

The full introduction of the new area of Evolution and Inheritance in the 2014 National Curriculum from September 2015 poses novel and challenging demands for schools and teachers. There is a need to interpret the Programmes of Study and to plan the sequence of delivery within the available science curriculum contact time. Schools will need to judge how to address some subtle and possibly elusive new concepts. The non-statutory PoS guidance offers some broad-brush statements without describing in detail the implications of the statutory requirements. Such lack of curriculum specificity was a concern emerging from the international comparative review of science curricula in high performing jurisdictions conducted as part of the Review of the National Curriculum in England (2012). The suggestion is that greater specification provides a clearer basis for teaching and learning, (see also Hunt, 2010). For primary teachers, some of the biological concepts may not be familiar and confidence in teaching this new area is unlikely to be high across the country, leaving teachers in a weak position to guide learners to access the required concepts. Judgments will have to be made about the sequence in which sub-topics are introduced, bearing in mind that a logical analysis is not always borne out by the conceptual trajectories in understanding that pupils actually follow.

Curriculum under-specification is problematic for teaching, but there is a precedent and proven research-based strategy for throwing light on this sort of problem. The kind of research reported here has an established pedigree in the work of Rosalind Driver's 'Children's Learning in Science' (CLIS, 1982-1989) project and in the Primary Science Processes and Concept Exploration Project (SPACE, 1989-1998) project funded by the Nuffield Foundation. The approach is maintained and developed in Project 2061, (AAAS, 2001, 2007) in 'mapping the growth of science understanding'. The title of the latter project, founded in 1985 at the time of the most recent visible approach of Halley's comet to the Earth, admitted the long-term nature of the task of creating an 'Atlas of scientific literacy'. The two volumes of the Atlas to date include in their compilations some research relevant to Evolution and Inheritance, but not with the coverage required by the 2014 science curriculum for England, nor the practical guidance for teaching that we have undertaken. The research reported here suggests how teaching and learning might proceed in this novel area and how understanding might be supported across Key Stages 1 and 2. The focus on progression and the collaborative involvement of teachers drawn from the relevant age profile ensured transition issues at KS1-2 were examined and taken into account. Guidelines for high quality instructional design depend upon the direct project involvement of practitioners and learners in the target age range. Our design-based research (DBR) approach (see ISDDE, http://www.isdde.org/) orientated project activity to provide tangible, robust, evidence-based guidance that will support teachers in implementing this new area of study. This report summarises the means by which the project has attempted to realise its intention to develop informed practical advice to assist the formative identification of conceptual difficulties and to suggest progressive learning sequences across the age range 5-11 years.

1.3 The National Curriculum context

The developmental perspective adopted by the researchers prioritised investigation of the progress of curricular concepts and skills over time. The intention was to explore how that growth might be supported across Key stages 1 and 2, challenging the idea of the introduction of discrete, single elements of the curriculum at Key Stage 2. Although the national curriculum emphasises the essential need for continuity and progression, Evolution and Inheritance is introduced at Y6 with all the antecedent foundational concepts receiving little explicit attention. Fossil formation, the prime source of evidence for evolution, appears at Y3. With foresight and careful planning for continuity, pupils in Y6 need not be suddenly confronted with complex ideas 'out of the blue'. In our view, the domain-specific content demands of the national curriculum relevant to teaching and learning Evolution and inheritance are interpreted as potentially present throughout the first two key stages.

At KS1, curricular expectations include a developing appreciation of different species of animals (including humans,) and plants. The foundations for understanding variability, change and ecology can be nurtured in some of these earlier experiences.

At KS2, children in Y3 are expected to be able to ***'describe in simple terms how fossils are formed when things that have lived are trapped within rock'.*** The capability to understand how fossils are formed is likely to be enhanced by early experiences in which children handle and observe the variety of fossils, explore the age of fossils and the places where fossils might be found. Other associated understandings are linked to geological processes and sedimentation in particular. A network of understandings of the variety of living things, habitats, structures and functions and what happens to different parts of organisms after death are likely to relate to developing understandings of fossil formation at Y3. At Y6, Evolution and inheritance is explicitly introduced as an area of study within biology. Children are expected 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.'

The research reported here was essentially concerned with how empirical enquiry might assist the teaching of these separate landmark ideas with greater continuity and progression.

The research activity was also mindful of the fact that the new science curriculum rightly emphasises essential links to be maintained between conceptual and procedural development - that is, between Working Scientifically and the science content or subject matter. As the process of 'argumentation' is another novel introduction to the KS2 science curriculum and an area we had explored previously with KS1 children (Russell & McGuigan, 2015a) we were keen to investigate the integration of science discourse and reasoning skills. The desirability of the incorporation of mathematics in science activities is also highlighted in the curriculum. This project report is able to contribute to strategies for the productive use of argumentation and mathematics skills to promote conceptual understanding.

The relevant statutory and guidance statements for Evolution and Inheritance and Working Scientifically are reproduced in full as Appendices 1 and 2.

1.4 Five emerging themes

It became apparent fairly early in the project that he complexity of the subject matter within Evolution and inheritance would necessitate organising the subject matter into manageable sub-domains. This was achieved by defining five themes that seemed to have conceptual coherence, yielded workable packages for teachers and children while offering sufficiently broad access for children across the 5-11 years age range. These five themes are i. Variation: ii. Fossils: iii. Inheritance and Selective breeding: iv. Deep time: v. Evolution (macroscopic view). Most of the reporting here and in associated documents refers to these five themes.

Section 2: Methods

2.1. Project personnel

Terry Russell and Linda McGuigan, both of the University of Liverpool, managed the project and benefitting from the occasional consultancy support of Prof. Geoffrey Parker FRS.

Twelve teachers across KS1 and 2 were initially recruited to the project in schools geographically situated in the following Local Authorities: Liverpool, Wirral, Warrington, Rochdale, Fylde, Lancashire and Blackburn with Darwen, Flintshire and Conway. In the course of the project, there were several changes in personnel due to pregnancy, workload issues and promotion. In one instance, the school offered another teacher to continue their involvement. The researchers were also able to identify one replacement teacher when required.

2.2. Project schedule

25 Feb 2014	Feb-Apr 2014	April 30 2014	May–June 2014	June 30 2014	Sep–Dec 2014	Jan-Mar 2015
First group meeting of core sample of teachers	Classroom based research, review & analysis	Second core group meeting	Classroom based research, review & analysis	Third core group meeting	Classroom based research review & analysis	Review Validate Consult

2.3. Participating teachers

2.3.1 Core sample

In order to make the focus explicit to participants from the outset, teachers were required to comment briefly on their willingness to engage with the following requirements:

- A qualified teacher having a particular interest and expertise in science education in general and the study methods and content area in particular.

- Willingness to adopt the project's pedagogical stance: that understanding the ideas children bring to their science learning is a critically important consideration for teachers. Participating teachers were committed to applying this philosophy to finding out children's ideas about Evolution and Inheritance and designing appropriate strategies on the basis of that evidence to help children to make progress.
- As the 2014 National Curriculum requires conceptual understanding to proceed with and through 'Working Scientifically', the exploration of pupils' ideas about Evolution and Inheritance proceeded hand in glove with that approach. Because the area of study is not readily amenable to direct investigation, pupils' handling of evidence from secondary sources was important, as were the skills of debating, where a case is presented, reflected upon and discussed critically.
- Involvement in the project required a commitment on the part of teachers to explore teaching and learning within the accepted current scientific understanding of Evolution and Inheritance. Project resources did not extend to exploring alternative views.
- As digital communications were a key means of information exchange, willingness to engage via an on-line forum (VOCAL, 'Virtual On-line Collaboration at Liverpool') was essential. (VOCAL is based on Microsoft Windows SharePoint.) While the project did not require special IT familiarity or expertise, it required regular use of VOCAL as a tool, with appropriate support.

2.3.2 Extended sample

The 12-teacher core sample in Northwest England was extended to other teachers interested in online participation via a presentation at the ASE annual conference 2014 in Birmingham and two short articles in the ASE journals, 'Education in Science' and 'Primary Science' (Russell & McGuigan, 2014b). The researchers made two presentations to primary teachers within two Northwest Local Authorities. A Schools and Colleges Officer of the Society of Biology forwarded the invitation to interested colleagues. The response to the national appeal was limited, with fifteen primary teachers and six secondary teachers signalling initial interest.

2.3.3. KS3 sample

The 2014 curriculum emphasises smooth progression through the Key Stages, together with the idea introduced for end of KS2 assessment of 'secondary readiness'. These two important ideas were the subject of consultation with a sample of KS3 teachers towards the end of the research, with some findings and recommendations from the KS1-2 research being made available to them for scrutiny and comment. The KS3-4 sample was drawn by invitation through social media and the newsletter of the Society of Biology as well as by contacting any teachers who had responded to the ASE's Education in Science (Russell & McGuigan, 2014a) notification of the research, together with its invitation to participate at a distance. The aspiration was for a sample of about 25, but in the event, direct contact proved a more successful method of recruiting KS3-4 respondents and the final total was eleven. Though drawing upon feedback from a smaller set of respondents than intended, responses were detailed and insightful, showing a high level of consistency in some important respects. Overall, the exercise was deemed to offer a helpful and realistically accurate perspective on 'secondary readiness' in relation to KS2 activities centred on Evolution and Inheritance.

2.4.Group meetings

Three scheduled project meetings, each of one-day, were held at the University of Liverpool. Face-to-face meetings functioned as opportunities to plan next steps and review practice. Sharing practices and discussing children's understandings proved motivational. Between meetings, project teachers shared insights, comments and questions with the group via VOCAL - a secure facility that permitted person-to-person communications and sharing of documents, images, ideas and plans. Additionally, the free password-protected, digital software 'Evernote' enabled all teachers to record multimedia evidence of their teaching and learning activities. These individual reflective journals were shared with the researchers.

2.5. Classroom visits

At least three visits were made to each classroom by the researchers and a total of 48 researcher visits of this kind were made. Photographic evidence of activity informed later reflective review, while direct contact provided opportunities to observe and discuss ideas and practices in real time with teachers and children.

2.6. Design-based research approach

The project used an iterative design based-research approach ('DBR', Anderson and Shattuck, 2012; Schoenfeld, 2009) to inform instructional design sequences in KS1-2 science. The researchers took responsibility for setting out the general conceptual research agenda. DBR combines science education research and theory with educational design and development intentions to generate evidence-based and ecologically valid recommendations for practice. The 'ecology' in this case comprises KS1 and KS2 classrooms in the state sector and the 'validity' refers to the direct involvement of teachers and children participating in the study being non-specialist in any attribute relevant to the enquiry. The research and design questions we posed sought to elucidate how the behaviours of teachers, classroom assistants and children might be influenced so as to move understanding and practices forward in what was a novel curricular area for all concerned. The collaborative DBR model is analogous to the formative assessment cycle, but from a curricular perspective. The approach provided a window on children's understanding suggestive of immediate and significant impacts on teaching and learning. The evidence generated and gathered in this manner provides functional and often innovative end products having immediate practical application as well as being worthy of wider dissemination.

The core group of teachers took up the challenge of exploring teaching and learning of Evolution and inheritance with enthusiasm, exercising greater autonomy than had been expected. That is, they each tended to re-frame the agenda set by the researchers as they saw fit, according to the needs and progress of the children they taught. This very positive response had various implications, discussed below.

The importance of a formative approach to teaching and learning was emphasized, implying that teachers should accept the need to identify children's current understanding in order to support progression in their developing ideas. Concept probes in the form of multimodal stimulus activities (seeded by the researchers and transformed in practice by teachers) encouraged children's expression and sharing of ideas. The design of the probes was subject to modification in response to teacher and children's feedback. Those activities regarded as most productive in the formative sense were identified and developed into reusable formative assessment probes (These are summarised in Section four of this report and published in a separate document, http://www.nuffieldfoundation.org/primary-pupils-understanding-evolution-and-inheritance.) Each teacher used VOCAL to make illustrative evidence of the emerging formative approaches and related outcomes available to the project. Emerging practices were exchanged, critiqued and developed across the group. Evidence of these activities and children's emerging understandings were combined to produce the five practical theme-related articles published in Primary Science, (Russell & McGuigan, 2014b, c.; 2015 b, c, d).

An innovative face-to-face coupling of research meetings and classroom observations with digital communications and on-line support worked well with the core sample.

2.7 Sources of data

Data were drawn from researcher observations of practice, pupils' classroom outputs, and teachers' 'Evernote' electronic journal and SharePoint entries that contributed to their summative reflective records of their project involvement. Significant information-gathering activity took place during researchers' visits to schools, including photography and collection of children's products. Within the twelve-month window available to the research, the approach to eliciting the ideas held by the pupils within the sample classes was cross-sectional (rather than longitudinal). The sources of data are summarised in Table 1.

Table 1. Summary of Core group project data sources

Age group	Core teacher sample	Number of children	Researchers' classroom observation visits	Researchers' support visits	Teachers' SharePoint entries	Teachers' Electronic journal entries	Teachers' reflective summative writing
4-7	3	90	12	2	6	50	3
8-9	4	120	12	3	22	38	3
10-11	4	120	17	2	37	59	4
Totals	11	330	41	7	65	147	10

The researchers accepted the fact that each teacher's professionalism dictated that they interpreted the research agenda according to the needs of children in their care. This proved a very positive direction to take in terms of teachers' commitment, ownership and classroom validity but at the cost of close comparability of elicitation data across ages. The implications for data collection were that anticipated frequency counts of the range of children's ideas being collected and plotted by age necessarily gave way to a more descriptive approach based on feasibility of the quality of intervention activity by broader age groups. In retrospect, this can be interpreted as classroom realities displacing a more 'experimental' approach, dictating that a much broader perspective had to be adopted than originally envisaged.

2.8 Data analysis

It is understood and accepted (Anderson and Shattuck, 2012) that practical and applied project outcomes are more likely from the use of DBR methodology than measurable effect sizes. Because DBR deals with complex interacting classroom variables, discrete measured outcomes tend to be relatively insignificant in the bigger picture. More weight is attached to the validation by the practitioners involved in the research and construction of curriculum support materials than to measured outcomes of pupils' assessed understanding. A fine grain approach had to give way to a coarser grain view to gain the wider developmental perspective. (Of course, there is a place for the latter approach, but the urgent practical priority in our research was to give an immediate and confident steer as to viable activities leading in the right direction over 6+ years.)

A core principle of the DBR approach is to assume complementarity between the skills of researchers and practitioners, recognising teachers' existing proficiencies with the age group and seeking to support their professional development when and where backing is sought. Early on in the research, the diverse ways in which teachers took ownership of the activities initiated by the researchers demonstrated that the unit of data could not be the conceptual understandings of a cross-sectional sub-sample of children drawn from each class. There were two main reasons for the shift away from the collection of frequency data. Firstly, teachers participated very actively and used their personal and professional judgement to re-cast the research objective in ways that they deemed suited the age group and particular characteristics and enthusiasms of the children they taught. Secondly, given this ownership they had taken on, it became neither possible nor desirable to constrain teachers' activities to repeat presentations and measures of the same elicitation activities across year groups, as has been the case in other research. In the latter case, the design of the interventions was more closely defined from outside the classroom and data collection more at arm's length. In the research we report, it was also the case that the more naturalistic approach, which asked broadly, 'How is the curriculum to be interpreted in practical ways within the span of age groups involved?' tended to combine elicitation and intervention into more seamless formative assessment cycles. The research was more participatory and ‘hands-on’ than experimental and ‘arms-length’.

Rather than the results being frequency counts by age group, the outcomes were forms of intervention that worked for teachers in various ways appropriate to the group taught. Thus, for example, in exploring variation, Early Years children encountered surprises in the course of their farm visit, learning that not all sheep are white. The research had prepared the visit to be sensitive to the notion of within-species variation, a perspective that would have been unlikely to be on the teachers’ agenda otherwise. At KS1, children grew plants and compared heights and numbers of leaves in groups of pots in order to generate what we referred to as a 'living graph'. The activity of germinating seeds was not a curricular innovation. Paying attention to differences, measuring and comparing growth and then grouping seedlings of similar height was the novel emphasis that focused attention on variation. By KS2, children were capable of measuring the variation in the circumference of apples in a supermarket pack, as well as comparing the distributions of hand spans and foot measurements. Reviewing data from various sources, these older children were beginning to use their mathematics skills to recognising the similarities in the shapes of the distributions they were recording. Younger children referred to this curve as ‘hill-shaped’, an excellent sense-making approximation to ‘normal distribution’.

The grounded, design based research approach adopted in this research led to recurring evidence of children’s conceptual struggles, increasing specification of classroom activities and identification of outcome understandings. Evidence in the form of examples of children’s work and teachers’ own illustrations of formative practice were the subject of critical dialogue between teachers and researchers. Emerging outcomes in the form of practices associated with children’s ideas were fed back to the project teachers for further reflection and practical critique. These discussions helped locate children’s understandings, identified associated understandings and appropriate next steps that might be described as ‘zones of proximal development’. The ways teachers adapted and modified consensual goals to meet the needs of the age group they taught resulted in the creation of replicable curriculum resources. Simultaneously, interventions were validated by elaborating, simplifying and fine-tuning them to children’s particular needs. Evidence of formative activities across the classes and year groups were collected and regarded as the salient and most valuable outcomes of the collaborative research activity.

2.9 Extended Sample

To extend the geographical reach of the project and the evidence on which it might draw, the approach included the possibility of involving an adventitious or extended sample. It was anticipated that this sample would operate entirely on-line. The response to the national invitation to participate at a distance was not as positive as had been hoped for. All twenty-one teachers who expressed preliminary interest were sent the initial ideas for activities. In practice, in a few instances researchers made a school visit either to observe activity or to support participation. Less than a third of teachers (Table 2) who received initial activities provided any feedback to the project.

Table 2. Summary of extended sample project data sources

Year group	Extended teacher sample	Number of children	Classroom observation visits	Support visits	Received activities	Provided feedback	No feedback offered
R-Y2	3	90	4	-	3	2	1
Y3-4	-	-	-	-	-	-	-
Y5-6	12	360	1	1	12	3	9
KS3	6	-	-	-	6	1	5

2.10 A replicable research strategy

It had been the intention that, on the basis of our prior experience in the area of constructivist research into conceptual change, the possibilities for extending techniques and strategies by making use of digital functionality would be explored. The possibilities offered by the combination of digital and face-to-face approaches might offer an efficient, innovative and replicable collaborative research strategy. Secure software applications offer the capability to support multimedia communication between members of the project group to take place 'any time, any place, 24/7'. Participants are enabled to record contributions or respond to one another's ideas at times that suit them. Ideas and practices can be shared rapidly across the project network. The accumulation of multimedia evidence of classroom practice and outcomes can be extensions of what has become commonplace everyday multimedia communications. The experiences of the extended sample within this project suggest that on-line digital activity on its own may be insufficient to encourage classroom-based research. Face-to-face meetings and classroom visits emerged as particularly motivating in terms of encouraging full participative and collaborative activity. Nonetheless, the digital functionality certainly contributed very positively to communications within the project's core group. It is probably the case that the almost unprecedented extent of change being introduced in education contemporaneously with this research was pre-occupying teachers and contributed to the inhibition of a wider, unsupported, participation.

2.11 Ethical guidelines

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 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 were shared with teachers prior to publication. This practice ensures 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)

2.12 Results: Project Outcomes

This Final Report is supported and complemented by essential further separate documents that report project outcomes. These can be accessed at www.nuffieldfoundation.org/primary-pupils-understanding-evolution-and-inheritance.

2.12.1 Project outcome 1 Literature review (Bibliography and Resources)

A review of research literature and informational materials useful for orientating the research was assembled initially. This grew throughout the duration of the project to include a wider set of resources, some of which will be more directly relevant to teachers' practices and pupils' interests. The bibliography and resource list continued to be refreshed throughout the project. The main sources informing the literature review are i) academic papers and books ii) exhibition and museum resources iii) websites, including informational or teaching resources and learning resources for access by children and iv) publications for children.

The bibliography is structured according to the following categories: 'progression', 'students' ideas', 'pedagogy', 'children's books', 'selected background science' and 'selected on-line resources'.

The idea of **progression** (Section A) in the development of understanding was of pre-eminent interest. Consequently, this aspect is given primacy in the review by being presented and discussed first and at greatest length.

Section B is about **Students' ideas** and deals with constructivist research into science concepts relevant to the domain, divided into younger and older age groups (the latter including teacher and other adults' ideas).

Section C, **Pedagogy,** reviews some materials that deal with teaching in the domain of Evolution and Inheritance, sub-divided into studies relevant to younger (C.1) and older (C.2) students and thirdly, consideration of 'working scientifically' (C.3) in this area of science.

A very limited and highly selective number of **children's books** are mentioned in Section D. In the case of narrative fiction (D.1), these might have been found particularly useful by participating teachers or useful to the introduction of relevant ideas. Some general principles relating to the use of narrative fiction are offered rather than any attempt at an exhaustive review of titles in section D.2, which very briefly reflects an interest that was aroused in the theoretical consideration of the role of narrative fiction in science education. The vast amount of non-fictional material available to children in both their domestic and school lives is barely touched upon in Section D.3. The sheer volume of material proved too daunting and the aspiration to have teachers review possible candidates for consideration or recommendation for colleagues was squeezed out of their project involvement by the time constraints of mainstream project commitments.

Section E, **Selected background science,** can only be a gesture towards an extremely extensive set of possibilities, given the vast resources available. The same consideration applies to Section F, **Selected Online resources**, where some extremely apposite and high quality examples are mentioned.

The bibliography is available at www.nuffieldfoundation.org/primary-pupils-understanding-evolution-and-inheritance.

2.12.2 Project Outcome 2 Formative Assessment Probes The set of formative assessment procedures or 'concept probes' for each of the five themes defined by the project are described in Section Three, below.

2.12.3 Project outcome 3 Teaching Interventions Practical summaries of the different qualities of children's ideas and associated targeted teaching activities within each of the five themes (Fossils, Variation, Inheritance and selective breeding, Deep Time and Evolution) are described in Section Four, below. A series of five articles (Russell & McGuigan, 2014 b, c., & 2015 b, c, d.) was accepted for publication in the Association for Science Education's journal, Primary Science. These articles speak directly to teachers, framing the context and outlining the research in the form of practical suggestions for assessment and intervention and so are to be seen as a very significant output.

2.10.4 Project outcome 4: Feedback from KS3-4 Given the authors' concern with conceptual progression, an important aspect of the study was to ensure that the teaching and learning at KS1-2 should support 'secondary readiness' and transition into KS3. In a brief follow-up study, KS3-4 teachers were invited to comment on their view of the extent to which the reported activities might prepare primary children effectively for further study at KS3-4. Section five summarises the outcomes of this element of the study. The report of teachers' views of secondary readiness is available at www.nuffieldfoundation.org/primary-pupils-understanding-evolution-and-inheritance.

2.12.5 Project outcome 5: Conceptual Trajectories There is criticism from some quarters (e.g., Duschl, 2011) of conceptual trajectories that are developed purely on the basis of curriculum analysis and the logic of the science. There is support for the 'bottom-up' development of sequences that start from children's early understandings (Evans, 2012). An important aspect of this study is that evidence from the classroom in the form of divergent formative practices is used to suggest conceptual trajectories from KS1-2. This approach combines curriculum analysis, an understanding of children's prior ideas and a pedagogy informed by formative assessment and classroom viability. Section six represents an attempt to sequence the ideas and associated formative practices in a manner that is likely to support conceptual progression.

Section 3: Formative Assessment Probes

A set of probes for each of the five themes into which the project enquiries were partitioned was edited to form practical project outcomes for classroom use more generally. Each theme has a number of probes associated with it together with suggestions for follow-up questions. The probes are not paper and pencil tests. They are designed to be engaging, open-ended and potentially interactive activities, proven within the research activity to be capable of harnessing children's interest, valuable in revealing children's ideas and practical in suggesting targeted interventions. Their basic function is to establish the quality and extent of children's current ideas. Insight into children's thinking provides essential information to teachers (and to the children themselves) as to the current state of their understanding: what they know and don't know, and their needs for further learning. Once these baselines are established, focused interventions are a more realistic possibility. It is also the case that the act of encouraging children to express their science ideas is in itself a form of intervention that encourages the development of thinking. This happens in two ways. Firstly, the act of articulating what were previously unformed ideas requires reflection and consequently, self-awareness of one's own ideas. Secondly, pupils hear alternative points of view expressed by other children that may be novel, insightful or in conflict with their own current beliefs. These experiences impact on their conceptual development. It is suggested that children should be invited to express their thoughts about Evolution and Inheritance and listen to, critique and reflect upon their own and one another's ideas. Drawing on our multimodal views of pedagogy and learning (Russell & McGuigan, 2003) we emphasise the importance of recognising that children can make their thinking public in a variety of ways: through speech, drawings, and actions or in 3-D models, for example. Initially expressed ideas can be developed through science discourse or 'working scientifically', using reasoned dialogue or argument in which the evidence and reasons for ideas are examined. The skills required to explore and critique one another's ideas and reasoning are consistent with the requirements of the 'speaking and listening' curriculum but the pattern of dialogue required in science may be novel. With planned opportunities, practice and support, teachers can help children to acquire the necessary skills to engage in science discourse. Children establish the habits of taking turns, listening carefully, expressing ideas and giving reasoned explanations; they should also critique, challenge and reflect upon their own and other's ideas. By these means, children and adults become resources for the development of understandings in arguments that draw on evidence gained from experience, secondary sources, educational visits, field trips and empirical enquiries

Formative Assessment Probes for Evolution and Inheritance

1. **Fossils**
    a. Drawing back through time: fossil formation
    b. Questions about fossil formation
2. **Variation**
    a. Questions probing understanding of within species variation in plants.
    b. Questions probing understanding of within species variation in animals.
    c. Measuring variability and recording in charts
3. **Inheritance and Selective Breeding**
    a. Using creativity and imagination 3D modelling to show how parent dogs might look like the puppies.
    b. Using creativity and imagination and 3D modelling to show how offspring might look like parents.
    c. Questions to elicit understanding of which behaviours and characteristics are transmitted
    d. Questions to elicit children's ideas about how offspring looks like its parents.
    e. Drawings to show which characteristics inherited.
    f. Questions to probe why characteristics inherited.
4. **Deep time**
    a. Questions to elicit ideas about the most significant events in deep time and the timing of those events.
    b. 2-D and 3-D models of Deep time
5. **Evolution (macroscopic perspective)**
    a. Questions probing children's understanding of extinction.
    b. Questions probing understanding of evolution
    c. Using story: Draw a series of pictures to show how evolution happens and add writing to explain ideas.
    d. Darwin's tree of life metaphor for evolution and cladograms
    e. Questions asking how tree of life helps understand evolution.
    f. 2-D and 3-D models to show ideas

The formative assessment probes are available for wider dissemination as a separate document at www http://www.ase.org.uk/journals/primary-science/2015/05/138/

Section 4: Theme-related Descriptions of Teaching Interventions

As deficits and difficulties in pupils' comprehension were diagnosed, all participants' attention focused on the aggregation of interventions aimed at remediating the problems identified. The participating teachers and researchers brought clarity of analysis, experience and creativity to the challenge of developing effective teaching and learning practices in response to the emerging evidence of children's ideas. A set of five summaries by the sub-domains was developed, with illustrations of classroom activities and pupils' products. Each summary provided a description of the qualities of learning, the recurrent struggles in understanding, together with a compilation of formative strategies for offering support to move learning forward. In order to make these summaries more widely available and to meet teachers' immediate needs, a series of articles was offered to and accepted by the Association for Science Education's journal, *Primary Science.*

The titles are:
1. Russell, T. & McGuigan, L. (2014b). Research into evolution and inheritance (with Dr. Who's help! *Primary Science.* Issue 134, September 19-21.
2. Russell, T. & McGuigan, L. (2014c). How long is a piece of string? *Primary Science*. Issue 135, November 22-25.
3. Russell, T. & McGuigan, L. (2015b). Why clone a sheep when they all look the same anyway? *Primary Science.* Issue 137, March 22-25.
4. Russell, T. & McGuigan, L. (2015c). Animals don't just grow feathers when they want to… *Primary Science*. Issue 138, May 18-21.
5. Russell, T. & McGuigan, L. (2015d). Why are there still apes if apes have changed into people?

These five articles are available at www http://www.ase.org.uk/journals/primary-science/2015/05/138/

4.1 Overview of general findings

- Children's motivation to explore their questions and ideas associated with Evolution and Inheritance was extremely high. Handling fossils, making models, searching for evidence and discussing ideas are practical experiences which children found engaging and fruitful.
- The interrelatedness of the five themes was an important recognition for teachers and the emphasis on unpacking of progression and interaction in ideas challenged any tendency to piecemeal approaches. The national curriculum as currently framed has probably tried to attend to progression without overburdening teachers in the overall volume of material. Our research suggests there is considerable scope for implementing learning sequences in a manner that promotes progression.
- While the study draws on evidence from a relatively small sample, the capabilities of the Early Years and KS1 children in accessing and appreciating some aspects of the five themes was striking. The research has identified key elements of foundational understanding.
- We emphasise scope for connectedness and coherence in children's understanding through the gradual accumulation of knowledge from other areas of biology in supporting progression in Evolution and Inheritance. For instance, children needed an understanding of plant life cycles in order to understand within-species variation amongst plants.
- Children across the age range demonstrated capabilities in presenting and justify their ideas. In the project classrooms, there was an expectation that children would listen and respond actively to each other's ideas. 'Research Meetings' (Lehrer & Schauble, 2012) were found to be a valuable way of encouraging children's argumentation and appreciation of the Nature of Science. (Ways of encouraging the wider adoption of the research meeting approach remain to be explored.)
- Narrative stories encouraged the expression of ideas and introduced some difficult ideas that children seemed content to explore through fiction. Iterations between non-fiction and fictional sources of information posed no difficulties for children. For teachers, clear links with the literacy curriculum could be exploited. Strong links were established between science and literacy in terms of children's speaking and listening and distinguishing between fact and fiction.
- Strong links were established between science and mathematics in the quantification of evidence and in plotting distributions.

4.2 Findings by each of five themes

4.2.1. Fossils

Children's understandings

- Children tended to focus on animal fossils and rarely mentioned plant fossils..
- Fossils were thought to be rare, difficult to find and precious or costly.
- They were though to be found randomly in caves, beaches etc.
- Wide estimates of the ages of fossils spanned weeks to millions of years.
- Children used the features and shape of the fossil and thought of life forms alive today having similar features as clues to the identity of the fossil.

Teaching and learning activities

- Visiting museums and field trips to explore a wide range of fossils.
- Handling, observing and recording real fossil specimens.
- Making sequenced drawings going back in time to show ideas about how fossils were formed.
- Observing and recording clay suspensions to explore sedimentation.
- Making 3-D models to show how the fossil might have looked as a living organism.
- Multimodal activities in which children move between real experiences, 2-D photographs and drawings and 3–D models.
- Non-fictional and fictional video to provide information about fossil formation, e.g. http://www.bbc.co.uk/nature/life/Ammonite#intro%.
- Narrative stories to explore fossil formation.
- Personal research and argumentation to find evidence to answer questions and justify claims about fossils.
- Discovery bottles which enabled children to observe and discuss sedimentation as an observable process as an analogy to the formation of layers of rock. These explorations provide early foundations for later study of the geological processes linked to fossil formation.
- Digital animations of fossil formation.
- Narrative story and role-play of Mary Anning.

4.2.2 Variation

Children's understandings

- Children tended not to appreciate variability within a population. Rather, they tend towards an essentialist view of living things - an assumption that living things within a species are all the same.

Teaching and learning activities

- Observation and measurement enquiries supported wider appreciation of the way in which populations of living things vary. These included measuring human variation (hand span, foot size) as well as in animals, plants, vegetables and fruits. (Sensitivity and caution is essential in relation to studying human variability.)
- Observation, counting and measurement of differences between the same species of

plants found locally and grown in class was productive.
- Measurement of the same kinds of fruit and vegetables such as apples in supermarket packages confirmed measurable variation.
- Observation, counting and measurement of the same species of animals such as tadpoles and stick insects extended possibilities for practical explorations.
- Recording measurement data in charts, graphs, etc., and discussion to link patterns with distributions in populations was productive.

4.2.3 Inheritance and Selective breeding

Children's understandings

- Children demonstrate awareness of resemblances between 'parents' and 'offspring'.
- Children tended not to distinguish between environmentally induced and innate characteristics
- The idea that inheritance was in part a random process was not appreciated. One commonly emerging idea across all age groups was that offspring would in some manner resemble both male and female parent.
- Towards the end of KS1 and up to end of KS2 there was a view that offspring receive equal characteristics from male and female parents.
- A small proportion of children in KS2 mentioned DNA in their descriptions of heritability.

Teaching and learning activities

- Discussion of resemblances between parents and offspring and how traits transmitted was viable.
- Narrative stories such as 'Little changes' (Taylor, 2013) and 'Wolves in the walls' (Gaiman & McKean, 2003) encouraged expression of ideas about inheritance, domestication, selective breeding and adaptation.
- Constructing 2-D and 3-D designer pets elicited ideas about inheritance over generations.
- Personal research helped to build an understanding of the kinds of features that might be selected as preferred traits for selective breeding of e.g., assistance dogs.
- Selective breeding for domestication, (meat, wool, vegetables) in contexts such as gardening, farming, horse and dog racing provided children with insights about how living things can change over generations.

4.2.4. Evolutionary time (Deep Time):

Children's understandings

- Children from Reception to Y6 offered a very wide range of durations to describe evolutionary events. For example, a Y6 pupil described fossil formation taking 28 weeks, another younger pupil, a billion years.

Teaching and learning activities

- Using commercially produced wall charts to explore the sequencing and timing of evolutionary change was informative and provoked considerable discussion and interpretative comment.
- Creating sequenced drawings of the timing and sequencing of events to be used as claims for argumentation provided a sense of ownership of and involvement in ideas.

- Creating different scale models or representations of evolutionary time such as 450-page book of important events, or a 45m or 450m trail of significant events made the appreciation of time more tangible and accessible.
- Explicit practice of reading, writing and speaking large numbers and translating between words and numbers revealed the need for continual revision in order to become at ease and familiar with the numbers required to describe evolutionary time.

4.2.5 Evolution (from a macroscopic perspective)

Children's understandings

- Children in upper KS1 and KS2 tended to be familiar with the term 'extinct'. Most were familiar with the extinction of dinosaurs. As children progressed towards Y6, they suggested a wider variety of extinct species including sabre tooth tiger and dodo. Children rarely mentioned examples of extinct plants.
- Understanding of the causes of mass extinction tended to centre around habitat destruction through climate change such as the ice age, meteorites and predation.
- Evolution was related to changes in a single living thing rather than populations. Changes in maturation such as metamorphosis or changing size in the course of lifetime growth were often offered as examples of evolution.
- Evolution tended to be thought of as the replacement of one species with another, better equipped, species.
- Children between Y2 and Y6 tended to describe humans as having evolved directly from primates. Transitions tended to be understood in terms of standing upright and having less hair. This understanding led some children to query why some apes still exist if humans had evolved from them.

Teaching and learning activities

- Narrative fiction stories to introduce ideas about evolution such as 'One smart fish', (Wormell, 2011) and 'Charlie and Kiwi' (New York Hall of Science, 2011) proved engaging and stimulating.
- Researching extinct and endangered species of animals and plants to develop knowledge and to help formulate claims for argumentation fostered evidence-gathering techniques.
- Using real tree branches as a concrete metaphor for the Tree of Life encouraged learning about common descent, relationships between species, and challenged linear thinking.
- Exploration of some key features of cladograms and how they might be used to demonstrate common descent, extinction and speciation (evolution of new species) complemented the Tree of Life metaphor.
- Children's secondary source research of Charles Darwin's life added a human dimension.
- Making 2-D and 3-D cladogram models to show ideas about common descent, relationships between species and extinction was innovative, challenging, but extremely worthwhile in consolidating understanding at the upper end of KS2.

Section 5: Feedback from KS3 and KS4 Biology teachers

5.1 Introduction

Given the authors' concern with conceptual progression, an important aspect of the KS1-2 study was the desire to ensure that the teaching and learning at KS1-2 should support 'secondary readiness' and transition into KS3. In a brief follow-up study, eleven geographically disparate KS3-4 biology teachers were invited to offer their views on the extent to which the reported activities might prepare primary children effectively for further study at KS3-4.

All KS3-4 respondents were provided with the five articles that summarised the Nuffield funded Evolution and inheritance research as published in the ASE's journal, 'Primary Science' (Russell and McGuigan, 2014 b, c; & 2015b,c,d). A structured response sheet was provided inviting comments against the five themes. A summary of the report is provided below.

5. 2 General overview

- All respondents were positive about the reported KS2 activities with some describing themselves as inspired by the suggestions for practice.
- Respondents tended to be impressed by the range and quality of KS1 -2 experiences as described.
- Most respondents were positive about the encouragement of the use of models and sequenced drawings at KS1-2.
- Most respondents believed the proposed activities offered a sound foundation for further study at KS3-4.
- A majority of respondents described a lack of progression in the coverage of evolution within the national curriculum at KS3-4.

5.3 Theme 1 Fossils

- The majority suggested experiences of handling fossils and an appreciation of fossil formation was key to understanding achieved by the end of KS2.
- An awareness of both plant and animal fossils was considered to be important
- Several suggested that the exploration of sedimentation could be extended so that depth of layer might be related to older fossilisations.
- It was generally recognised that the full range of activities described would be an unlikely provision in all KS2 feeder schools.
- Three quarters believed that an awareness of fossils as evidence of past life forms was important, especially when treated as a source of evidence for evolution.

5.4 Theme 2 Variation

- The KS2 activities were understood to prepare children with important mathematics skills and an understanding of variation at KS3.
- The encouragement of measuring, recording and presenting data as an integrated element of science enquiries was viewed as valuable and timely preparation for KS3-4.
- Two fifths of the sample of KS3-4 teachers suggested the distinction between discontinuous and continuous data should be introduced more explicitly at KS2.
- One fifth of KS3 respondents believed an awareness of DNA might be useful preparation for KS3-4 study.

5.5 Theme 3 Inheritance and selective breeding

- KS3-4 respondents approved of the context of selective breeding as an entry point to Evolution and Inheritance.
- Although a quarter of respondents reported teaching selective breeding at KS3, about a half mentioned that selective breeding was not in the revised KS3 National Curriculum. Prior experiences of selective breeding in preparation for KS4 were recognised as important.
- Two fifths of KS3-4 teachers responded positively to the use of narrative fiction as offering access to difficult ideas – an unexpected positive outcome, albeit from a minority.
- One quarter of the sample of KS3-4 respondents' suggested selective breeding offered productive opportunities for the development of argumentation skills.

5.6 Theme 4 Deep Time

- Three quarters of KS3-4 responses demonstrated unequivocal awareness of some of the difficulties KS3 students faced in understanding the magnitude and scale of deep time.
- The KS2 approach seemed to be valued by KS3-4 respondents, all of whom welcomed the activities as appropriate preparation for KS3.
- About two thirds viewed the ideas suggested for children to create their own models of timelines as particularly valuable.

5.7 Theme 5 Evolution

- The KS1-2 classroom activities that dealt with a macroscopic idea of evolution were valued by all of the KS3 respondents not just in terms of readying pupils for secondary transfer, but as something to be taken up at KS3.

- The Tree of Life as a scaffold for a macroscopic appreciation of evolutionary changes over time is innovative at KS1-2. Three quarters of KS3 respondents welcomed the introduction of cladograms and Tree of Life to KS2 pupils, even though cladograms are typically introduced only at KS4.

- While two thirds of KS3 respondents indicated that students were not introduced to either the Tree of Life metaphor or to cladograms, all respondents indicated that KS3 students should be introduced to both of these representational forms.

The full report, Evolution and Inheritance at KS1-2: Feedback from KS3 and KS4 Biology teachers' is available at www http://www.ase.org.uk/journals/primary-science/2015/05/138/

Section 6: Conceptual Trajectories

This emphasis on progression needs to be justified explicitly as resting on assumptions about the importance of a formative approach to teaching and learning. In this perspective, teachers accept the need to identify a learner's current understanding and support progressive movement, guided by their pedagogical content knowledge ('PCK', Shulman, 1986). Once developmental sequences are mooted, practical targeted interventions will be more apparent. Even tentative descriptions of developmental trajectories support teachers' formative use by helping them to decide zones of proximal development. 'Teaching and learning sequences do not exist ready-formed, waiting to reveal themselves. They must be constructed by human minds, pieced together by drawing on evidence from within a complex set of interacting variables. Plotting a developmental journey is akin to scanning a rock face to discern likely finger and toeholds: it is a challenge that requires expertise and there may well be more than one route. Once scaled, the ascent is validated and others may follow more readily. Practitioners' skills and experience, resources within settings and children's capabilities individually and across the focal age range all vary. This kind of research demands evidence-based acts of judgment in order for learning trajectories to be posited on the basis of theoretical advances. In DBR methodology, this is acknowledged to be an iterative process in which design refinements are to be expected. The utility for teachers' practices and children's progress are the final tests. It is within this framework of thinking that we suggest how development may proceed. The grounded, design based research approach led to increasing specification of recurring aspects of behaviour that, when informed by dialogue with teachers and subjected to theoretical reflection, may be aggregated and sequenced to describe more complex developmental patterns' (Russell & McGuigan, 2015a).

6.1 Fossils

An outline of progressive sequence

What Fossils are

Almost without exception, children tend to know the word 'fossil' from their out-of-school experiences. They are aware of the great age of fossils and that they are some form of 'rock' related to something that was once alive – perhaps something that was alive that has been turned to rock.

Fossils are associated with animals – most often dinosaurs - rather than plants. They are likely to be considered to be rare and very precious.

Fossils are often regarded as what remains of entire organisms, perhaps because of the prevalence of entire well-prepared specimens of trilobites and ammonites. There is also likely to be frequent reference to fossils as being parts of the bodies of dinosaurs. There is unlikely to be any intuitive assumption encountered that the fossil body is a replacement substance for the original tissue of the once-living organism.

Many children might have some first-hand experience of fossils from their home environment, possibly related to the family's socio-economic circumstances.

It is widely assumed that a fossil can be identified by the fact that it has some sort of pattern.

We encountered no awareness of the existence or the enormous numbers and distribution of, microfossils – fossil diatoms, etc.

Where fossils are to be found

Younger children are likely to assume that fossils can turn up wherever they might take a walk or begin to dig. They are assumed to be buried under the ground, like archaeological artefacts.

The fact that fossils in the UK have some strong associations with coastal erosion of cliffs (reinforced by the story of Mary Anning that the National Curriculum promotes) may be responsible for frequent references to fossils being found in rocky seashore environments.

How fossils are formed

Film of cobbles being split open with a hammer to reveal the perfect spiral of an ammonite inside is not uncommon. The

Illustrative activity

Primary Science Issue 134 presents illustrative examples of the activities and experiences offered. Section 4 of this report provides a summary of children's prior ideas and formative activities.

Across KS1 and KS2, children were offered experiences to handle, observe, research and record a variety of fossils including plant fossils.

Children's individual research enquiries, making 3-D models of living organisms and argumentation helped children appreciate what fossils had been like as living organisms and as evidence of earlier life forms.

Visits to museums and local 'fossil hunts' helped children appreciate where fossils might be located.

Drawing back in time and using these drawings as a basis for argumentation conundrum of perfect forms encased in rock may be further confounded by the language in which the search for the answer to the mystery is framed, typically, 'How did the fossil *get inside* the rock?', suggesting that it somehow travelled to the interior from outside. This analysis helps to make sense of the not uncommon suggestion from children that a fossil that was resting on a rock has in some manner 'sunk into' the rock. Various support materials offer sequenced picture strips showing the replacement of tissue through mineralisation processes, but the sequence is possibly counter-intuitive.

encouraged the expression of ideas associated with fossil formation.

Observing and recording clay suspensions forming sediments, along with video, cartoons and discussion provided insights into fossil formation.

Fossils in KS3-4

At KS3, the subject matter of fossils may not be addressed. If it is, the emphasis seems to be in the direction of an important source of evidence for evolution and the fact therefore that exposure to fossils should be a stimulus for thinking and Working Scientifically. KS3 fossils are discussed mostly in conjunction with ideas of geological time. The expression 'Deep Time' might be more likely to be used at KS4 in the context of the rock cycle. Fossils appear again at KS4, this time properly linked to evolution. There may be a lack of continuity in the consideration of fossils *per se* and as a source of evidence for evolution. At KS4 most recent guidance from the Department for Education states:
'**describe the evidence for evolution, including fossils and antibiotic resistance in bacteria**'

6.2 Variation

Why Variation?

The 'bottom line' in considerations of progression in the theme of Variation is the establishment of the idea of species as *populations* having inherent variability. This understanding must displace assumptions about species as sets of identical individuals. The potentially confounding idea is that of 'essentialism'. In essentialist thinking about species, the assumption is of some quintessential quality or nature as defining species membership. In this view, the (relatively small) divergences in appearance between species set members are attributed to aberrations or accidents. Essentialist thinking has generated a convergence of interest between those who research the history and philosophy of science (e.g. Winsor, 2003; Stamos, 2005) and those who explore this mode of thinking from the perspective of developmental psychology (e.g. Gelman et.al., 1994).

Primary Science Issue 137 presents illustrative examples of the activities and experiences offered. Section 4 in this report provides a summary of children's prior ideas and formative activities.

Essentialism

The essentialist mode of thinking seems to predispose young children to think of organisms of any given species as fundamentally and effectively alike, or even identical, barring slight or superficial differences. (It is likely that this way of thinking prevails into adult life in many situations.) Since it is only variation within a species that makes evolutionary change possible – by exploiting slight differences that confer advantages on some individuals for survival and breeding

Reception and year 1 children revealed ideas that all sheep are white during a farm visit. Their experiences and discussions as they handled and observed the different sheep targeted their reasoning.

success – recognising variation within a population is a prerequisite to understanding change across generations.

Recognising within-species differences

With experience and focussed observation, young children will come to realise that not all familiar domestic animals are identical. Farm and zoo visits allow close observation to establish individual variation. Behavioural differences can also be observed: children tend to be very alert in spotting differences in behaviours of dogs and other pets. Even tadpoles reveal differences in, e.g. their rate of growth or metamorphoses.

Children in a year 1 & 2 class expected that all seeds would grow and develop into identical plants. These and other similar experiences that targetted children's essentialist reasoning are explored in *Primary Science* Issue 137.

At a more advanced level, it may be learned that scientists who study different animals recognise e.g. individual elephants. Individual Bewick swans and Whooper swans can be identified by their unique bill patterns. The pioneering work of Jane Goodall (2010) with chimpanzees and Diane Fossey (2001) with Mountain gorillas established as normal practice the identification of individuals' identities.

Measuring, recording and displaying continuous differences

Children can measure differences between certain attributes such as hand span or foot size as well as behaviours such as time to run a distance, length of a standing jump, and so on. This kind of activity encourages the transition from observation to measurement. The data provide information about the range of differences in any group and allow individual differences to be ordered on a scale of measurement.

Children's measurement activities centred around humans, other animals and plants helped them to describe differences.

A next step is to make frequency counts of the different measures taken. This requires intervals to be agreed so that clusters or groups of measures can be clumped together. For example, for hand span, the groups may be ordered into 10 or 20 mm sets. Then it becomes possible to count the number of instances in each set as frequency counts.

Once frequency counts have been made, the data can be plotted in the form of how many instances in each set on the vertical (y) axis and the actual measurement ranges on the horizontal axis. The result will be (for many such measurements of attributes in the living world) a normal or 'hill-shaped' distribution.

Children's measurement and recording of differences between people and plants are reported in *Primary Science* Issue 137.

Comparisons between different measures can be made by observing the shape of different distributions – for example, the curves produced by hand measurements and foot measurements – with the possibility of noting that the basic curve shape remains constant.

The range of measurements included in each set need to be supported by teachers in order to provide enough data points to enable a curved shape in the data to be identified. For this reason, the way the data are combined into clusters is likely to need teacher guidance. (Clumping data to generate roughly 6-8 data pairs allows the possibility of plotting a 'hill-shaped' curve.)

Measuring, recording and displaying discontinuous differences

Discontinuous differences, such as hair colour, eye colour etc., can be demonstrated by children who are the owners of different attributes allocating themselves to sets. Domesticated animals and pets also provide suitable subject matter for considering discontinuous traits. Various fur types and pigmentations occur in breeds of guinea pig and rabbit, as well as cats and dogs. Pigeons are also selectively bred to favour various characteristics of form and behaviour, as noted by Darwin.

Children's attempts to order measure handspans, heights of plants, etc. and to record these as graphs and their emerging descriptions of the pattern in the distribution are examined in *Primary Science* Issue 137.

Variation in KS3-4

Whereas in KS1-2 both continuous and discontinuous variables are discussed as specific traits, in KS3 these differences are treated more explicitly as different qualities of plotted variables on graphs. It is possible that this distinction may be brought to children's attention at the upper end of KS2, where two continuous variables plotted against one another is a realistic expectation for many.

The other important distinction at KS3-4 is that mechanisms underlying the expression of traits begin to be introduced at the microscopic or molecular level.

6.3 Inheritance and Selective Breeding

Young children soon learn that offspring resemble their parents. The fact that in some species the emergence of that similarity takes time to surface (as in the shift from the grey down of cygnets to the white feathers of adult swans) is celebrated in children's songs and stories. The special case of metamorphosis in some insects and amphibians is also readily accepted. The fact that seeds have a pre-determined relationship with particular parent plants may be a slightly more elusive appreciation than the link between parents and progeny in animals.

Primary Science Issue 138 presents illustrative examples of the activities and experiences offered. Section 4 in this report provides a summary of the context of teaching and learning activities.

There are clear reasons why change over generations is an idea more accessible through the process of selective breeding than natural selection. The domesticated animals that are selectively bred show more diversity than their 'wild' forebears. (A pair of dogs can show far greater variation than a pair of wolves.) Also, the effects in offspring are far more quickly apparent. Selective breeding, where humans control the selection pressure, is therefore a useful model or analogue to introduce in advance of evolution by natural selection.

Across the year groups, discussion of resemblances between parents and offspring was possible.

Making 2-D and 3-D designer pets provided all age groups with the opportunity to think about resemblances between parents and offspring and how they might be transmitted.

Children are able to accept readily that the puppies or kittens in a litter are likely to show significant differences in appearance and behaviour. The possibility of breeding to enhance a desirable trait is accepted, as is the idea that the attribute that is sought should be present in the parents. There is unlikely to be any clear idea as to the respective contributions of the male and female parents on the

Contexts such as, farming, gardening, horse breeding, dog breeding and the need for assistance dogs drew on some characteristics of the progeny. These ideas do not seem to be dependent on sex education: children are happy to discuss animals 'breeding' or being 'bred' without any need for explicit detail of the mechanics as essential foundations for their hypotheses about outcomes in the progeny. Children who have experience of the breeding of domesticated animals of pets are more likely to be familiar with terms such as 'thoroughbred'.

Older children readily accept and appreciate that animals in the wild are influenced in their form and behaviour by their environment. Plants are more likely to be included in this line of thinking than they are to be mentioned in other areas related to inheritance. A large range of examples is likely to be willingly accepted as being 'adapted' or showing 'adaptations': owls, birds of prey more generally, camels, polar bears, etc., all of which manifest a visible link between form and survival function. However, children's explanations as to how or why these adaptations have arisen are very likely to be teleological and may tend to be at the individual level. That is, the change in form is likely to be assumed to be purposeful, somehow the result of the individual animal's need or intention, rather than the result of an advantageous trait that results in enhanced survival value and breeding success that promulgates the trait in the population of the species as a whole. Adaptive changes are also frequently assumed to be the result of the transmission of life span changes to offspring (as in assumptions that the sons of blacksmiths would inherit muscle strength as the result of the father's occupational behaviour).

children's personal experiences and engaged their interest in selective breeding.

Personal research and classification activities helped children learn about some of the diverse traits of different animals and plants.
Narrative stories such as 'Little changes ' and 'Wolves in the walls' encouraged expression of ideas about inheritance, domestication, selective breeding and adaptation.

Enquiries and discussions associated with selective breeding generated insights into how living things might change across generations and the effects on populations.
Discussion activities revealed support for the encouragement of reproduction of preferred traits in the selective breeding context.
The effect on survival rates of selective breeding on those animals lacking preferred traits challenged children's views of fairness: they were disposed to support the 'underdog' and the idea of culling never arose.
Children's discussions tended to centre on ways of supporting the weakest individuals in the population, bringing them 'up to speed' through training or environmental interventions.

Inheritance and Selective Breeding in KS3-4

Selective breeding seems to be addressed at KS4 rather than KS3, possibly because advances in technology, including genetic engineering, have become more prevalent and need to be present on the KS3 curriculum. The biological mechanisms are more complicated, requiring a microscopic or molecular framework that is reflected in changes to the KS3 approach.

With sexual reproduction not likely to have been introduced until upper KS2, in KS3 the exchange of genetic material between male and female adults to form the zygote offers a route for discussing the contributions of each parent to the offspring. The 'official' position at KS3-4 is defined by the Department of Education, 2013 National Curriculum specification (in bold font), the requirement being to cover: **Heredity as the process by which genetic information is transmitted from one generation to the next.**
When selective breeding is used as exemplification, care has to be

taken to emphasise that breeds are not the same as species as this confusion can be witnessed at KS3-4.

At KS3, more emphasis will be placed on environmental factors being identified as the pressure on selection (rather than human control of breeding). Environmental factors and adaptation should have been introduced at KS2, but without detail of the mechanisms underpinning natural selection such as enhanced survival value, breeding success and the extinction of non-adapting variation.

6.4 Deep Time

The main issue in relation to pupils' understanding of deep time is the enormous magnitude of the units of measurement (millions of years ago, mya) and the overall span of the scale of time that has to be comprehended (approximately 4.5 billion years). The sense-making that must underpin such comprehension is beyond direct human experience. While deep time cannot be experienced by humans directly, the concept is essential to an appreciation of evolutionary change. The reasoning deployed in terms of understanding temporal sequencing and duration is an extension of that used to appreciate 'everyday' time. 'Deep' or evolutionary time has to be constructed as a mental representation, abstracted from concrete supporting evidence via a series of logical steps. From this perspective, the accessibility to pupils of the different modes by which the idea of Deep Time might be represented is the critically important consideration.

Primary Science Issue 135, presents illustrative examples of the activities and experiences offered. Section 4 in this report provides a summary of children's prior ideas and formative activities

Experience of the passage of conventional time

Appreciation of the passage of time starts with the experienced human scale of events (periods of the day: morning, midday, afternoon, evening, night time) and gradually extends to the use of very much smaller and very much larger segments.
Vernacular expressions approximate to measured time intervals of measured time: 'It'll only take a second'; 'Wait a minute'; 'I've been waiting ages'. Informal units include 'number of sleeps' to describe periods of days and nights.
Children and adults may start to separate time into 'now', and 'long, long ago'. The common experience of underestimating the timing of past events is familiar to many adults and may underpin the vernacular. 'How time flies'. A parallel tendency to underestimate applies to ideas about evolutionary time scales.

While young children may be able to sequence familiar daily routines they tend experience difficulties sequencing events over longer periods of time. Ordering events in Deep time is thought to involve the same reasoning processes as ordering events in conventional time. The magnitude of the numbers involved and popular images in comics, cards etc. that for instance put people in the same time as dinosaurs etc. might be thought of as being influential (Children's understanding of the formation of fossils ranged from 28 weeks to hundreds of thousands of years)

Scales for the Measurement of Time

Telling the time. Scale and measurement of time is introduced through 'telling the time', using analogue circular clock face and the measurement units of hours and minutes, and later, seconds. Fractions of a second come later: tenths, hundredths (probably becoming familiar through timed sporting events such as sprints).

Children's estimates of the timing of events in deep time such as the formation of fossils ranged from 28 weeks to hundreds of thousands of years. The explicit introduction of discussion of large

Introduction of the calendar. With the introduction of the calendar, the scale of the whole year is introduced: day, week, month, year, and the passage of years A.D. (in the Christian calendar). Aggregations of years may be introduced in History lessons, probably using time lines: decade, century, millennium, perhaps thousands of years used to describe human history.

Introducing the scale of Deep Time. MYA or 'millions of years ago' will need to be introduced to describe 'geological' or 'deep time'. The very large numbers involved requires mastery of the decimal or base ten number system and learning how to read and say large numbers (hundred, thousand, hundred thousand, million, billion, trillion). Writing these numbers as words and in numeric form has to be mastered. Translations between verbal and numeric forms (e.g. 'million' and 1,000,000) and mixtures of the two (as in 4.5 billion) helps to consolidate understanding, as does learning to use of power of ten as a superscript.

Familiarity through constant use will lead to the development of a facility in handling the enormous magnitudes concerned. The reality of most people's everyday lives does not require such constant usage.

numbers was encouraged across the age range so that the magnitude of the measurement of deep time was embedded in children's vocabulary. Children researched the timing of events and towards the end of KS1 and KS2 experimented with recording the large numbers associated with deep time.

Commercial time lines were explored across the age range and engaged children's attention. They introduced the sequencing, timing and duration of events. Issues of scale were brought to children's attention. Later, these charts were used as points of reference as children decided where events should be placed on their own models of time. (See Primary Science 135, where year 2 children's interaction with a commercial time line is discussed)

Representations of Deep Time

Clock face

Once 'telling the time' using the 12-hour clock has been established, the analogue of the passage of the hour hand is useful in re-describing the relative passage of time marking important events in the history of the Earth. (Twelve hours or 43,200 seconds is used to represent 4.5 billion years, or very approximately, one second stands for about 100,000 years.)

Time lines

Straight 'time lines' are used in history to describe the relatively short passage of time over hundreds and perhaps thousands of years. Similar straight time lines can be used in various contexts, using 4.5 billion as the duration to be represented.
4.5 cm can be used by children with pencil and paper.
45 cm can fit neatly onto an Interactive Whiteboard.
4500 mm (450 cm or 4.5 m) can be used indoors, in a classroom.
45 metres can be used in a long corridor or outside in the school grounds or playground.
450 metres might be possible in school playing fields.

Spirals

Some posters use a spiral representation as the image offers an economical and space-efficient compressed representation.

Pages of a Book

Four and a half billion years can be represented by the pages of a book using both sides of 225 sheets of paper, each side standing for 20 million years.

Children and their teachers developed models to represent the order in which some events occurred in deep time and the timing of these events. Children in consultation with teachers and using argumentation techniques decided the events to be included. They researched when the events occurred and used science discourse to negotiate how events should be presented in their model. Many children needed teacher support to develop and implement an accurate scale. Those developing a 450 or 45 metre time line used trundle wheels to ensure accuracy. Images were tied to trees or stakes and dated to sure the passage of time. In a year 2 class, children made a book of deep time as a resource for the next class. Their teacher was impressed with their research skills, their willingness to engage with a scale that meant most events were at the front of the book and the capabilities to handle a model that went backwards in time. (See Primary Science 135, where the construction of time lines at KS1 &2 is discussed.)

Children's research from Reception to Year 6 explored the sequencing and timing of specific events. Reception children focused on identifying animals that had become extinct while other's researched a wider range of events corresponding to their interests. The idea of Research meetings in which children presented and exchanged evidence was encouraged.

Awareness of duration of significant events e.g.
Human lifespan
Human and other animals' 'generational' time
Age of the universe
Age of the Earth and other planets
Age of life on Earth
Age of modern humans on Earth

Awareness of significant events that mark the passage of time e.g.
Extinction of the dinosaurs
The emergence of animals from water to land
Earliest human ancestors
(See, British Geological Society *Geological Timeline*: **www.bgs.ac.uk/discoveringGeology/time/timeline/Timeline_Teachers_Page.pdf)**

Deep Time in KS3-4
Deep Time might be covered thoroughly in KS3 in the study of geology and the rock cycle, possibly mentioning radiometrics or carbon dating. Deep Time is frequently linked to the history of the universe at KS3-4, but there may be little in the way of crossover links with evolution. Evolutionary time might not be revisited until KS4, the DfE making no reference to deep or evolutionary time at KS3. However, KS3 and KS4 pupils may study space and the Big Bang theory, as well as the life cycle of stars, the age of the universe, the formation of the solar system and life on Earth, referencing Hutton (1959) and Wegener (1966), and the theory of plate tectonics. At KS4, (Department for Education 2014), the idea of deep time can be used across the syllabus, for example, when discussing evidence for evolution, the age of the universe and the development of the Earth's atmosphere.

A representation that might be used is an idea from Richard Dawkins, 2012 'The Magic of Reality' where the students conduct thought experiments including imagining a photo of themselves on top of a pile of photos 40 miles long.

6.5 A Macroscopic perspective on Evolution

By a 'macroscopic perspective on evolution', we mean a broad understanding, or the big picture, unimpeded by difficult detail. To this end, in the first instance the intention is to convey something more descriptive than explanatory, towards the establishment of the broad drift of the story. 'Story' is in fact an important and useful word, since the use of narrative fiction allows the breadth and scale of events to be compressed to manageable proportions that even young children can assimilate. The other extremely important scaffold for understanding evolution in this general sense is the Tree of Life

Primary Science Issue 139 presents illustrative examples of the activities and experiences offered. Section 4 in this report provides a summary of children's prior ideas and formative activities.

Real branches were used to explore with children the ideas of metaphor to represent the common ancestry (or common descent) and branching diversification of all organisms. (Incidentally, it is commonly accepted that in the light of advances in genetic understanding, lateral gene transfer between unicellular organisms makes the 'tree' in some senses more of a thicket. This in no manner undermines the metaphor's heuristic value. See, for example, http://www.texscience.org/reports/sboe-tree-life-2009feb7.htm)

common descent and the relationships between groups of different living things.

In essence, the target is to bring KS1-2 children to an understanding of the two basic facts of evolution. Firstly, that organisms change (elaborated towards 'have changed, are changing and will continue to change') and that such changes happen over time (in fact, enormous spans of time by comparison with human lifetimes). The other critical understanding to work towards is that evolutionary changes are most helpfully viewed as branching, rather than linear. Ways of representing the Tree of Life as 3-D rather than simply 2-D help to combat the prevailing assumption of linearity.

The role of narrative fiction

Not all teachers or science educators may feel comfortable with the use of fiction to convey scientific information. There are likely to be understandable concerns about anthropomorphism, intentionality driving evolutionary change and so forth. Our conviction is that narrative fiction can serve an indispensible function, the more so when tempered by discussions centred on the distinction between fact and fiction – skills that are transferable from the literacy curriculum.

The role of fictional frameworks to initiate and structure dialogic processes

Narrative fiction can be used as a starting point for Working Scientifically when claims made in the story are subjected to debate as claims and counterclaims.

Narrative fiction of 'Charlie and Kiwi' and 'One smart fish' used to introduce challenging ideas

Use of Cladograms

While cladograms are not familiar modes of data representation in KS2 classrooms, they complement the Tree of Life metaphor extremely well. Individual 'clades' or branches can be illustrated with relationships between species that have diverged over time capable of being quantified in various ways.

Children made 2-D and 3-D cladograms and used these as the bases for claims that could be derived from the logic of the diagrams. They could then present and critique one another's understandings about evolution.

Evolution in KS3-4

The suggestion is that evolution as a topic drops off the radar at KS3, and cladograms also have to wait for KS4. From the most recent KS4 Guidance for Single Science (April 2014):

Describe evolution as a change in the inherited characteristics of a population over time through a process of natural selection which may result in the formation of new species.

Explain the impact of the selective breeding of food plants and domesticated animals.

Nervousness about suggesting the introduction of cladograms at KS2 was put at ease by feedback from KS3-4.

Section 7: Dissemination

7.1 Conference presentations

Table 3. Presentation of the Evolution and inheritance KS1-2 project updates and outcomes

Location	Participants	Number attending
ASE 2014 Birmingham	KS1-3 (5-16 yrs.)	40
Wirral	KS1-2 (5-11 yrs.)	35
Blackpool LA	KS1-3 (5-16 yrs.)	40
ASE 2015 Reading	KS1-3 (5-16 yrs.), teachers, researchers, museum educators, etc.	60

A summary of presentations to date is provided in Table 3. Emerging messages as to how teaching and learning about Evolution and Inheritance might be facilitated have been, and will be, disseminated through conference presentations. The Association for Science Education (ASE) Annual Conference, January 2014, University of Birmingham, provided an early opportunity to alert the profession to the project aims and to its collaborative methodology. The brief presentation included an invitation to delegates from across the country to participate on-line and at a distance. A second presentation was delivered at the ASE Annual Conference, January 2015, University of Reading, in which the five key themes identified within the project and the formative interventions associated with each theme were shared with teachers, teacher educators and museum education staff. Two invited presentations have been made, to Fylde and Wirral Local Authorities.

A further two presentations have been accepted for the European Science Education Research Association (ESERA) Conference Helsinki September 2015. 'Introducing evolution and inheritance to the primary curriculum in England' and 'Essentialism v. variation: Are all sheep white?'

7.2 Publications

A central feature of the project has been the active involvement of teachers and children. This has ensured the generalizability of the outcomes to classroom practice. To safeguard the messages about teaching and learning reaching practitioners, the project activities have been disseminated through the Association for Science Educational professional journal, Primary Science. The four articles published to date relate to teaching and learning about 'Deep time' (September 2014), 'Fossils' (November 2014), 'Variation' (March 2015) and 'Inheritance and selective breeding' (May 2015). A fifth article 'Evolution' has been accepted for the August-September 2015 issue. A paper presenting some of the Early Years practices associated with Variation has been submitted to the ASE's journal of Emergent Science: 'Using multimodal strategies to challenge Early Years children's essentialist beliefs'.

The authors intend to continue to reflect upon the implications of this research, invite feedback and seek further publishing opportunities in relation to the outcomes of the project.

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Acknowledgement
The Nuffield Foundation is an endowed charitable trust that aims to improve social well-being in the widest sense. It funds research and innovation in education and social policy and also works to build capacity in education, science and social science research. The Nuffield Foundation has funded this project, but the views expressed are those of the authors and not necessarily those of the Foundation. More information is available at www.nuffieldfoundation.org

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Appendix 1

Table 1 Programme of Study and non-statutory requirements for KS 1 and 2

	Statutory requirements	Notes and guidance (non-statutory)
KS1 Year 1	**Animals including humans** describe and compare the structure of a variety of common animals (fish, amphibians, reptiles, birds and mammals, including pets)	Pupils should use the local environment throughout the year to explore and answer questions about animals in their habitat. They should understand how to take care of animals taken from their local environment and the need to return them safely after study. Pupils should become familiar with the common names of some fish, amphibians, reptiles, birds and mammals, including those that are kept as pets. Pupils should have plenty of opportunities to learn the names of the main body parts (including head, neck, arms, elbows, legs, knees, face, ears, eyes, hair, mouth, teeth) through games, actions, songs and rhymes. Pupils might work scientifically by: using their observations to compare and contrast animals at first hand or through videos and photographs, describing how they identify and group them; grouping animals according to what they eat; and using their senses to compare different textures, sounds and smells.
KS1 Year 2	**Living things and their habitats** explore and compare the differences between things that are living, dead, and things that have never been alive 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, and how they depend on each other identify and name a variety of plants and animals in their habitats, including micro-habitats	Pupils should be introduced to the terms 'habitat' (a natural environment or home of a variety of plants and animals) and 'micro-habitat' (a very small habitat, for example for woodlice under stones, logs or leaf litter). They should raise and answer questions about the local environment that help them to identify and study a variety of plants and animals within their habitat and observe how living things depend on each other, for example, plants serving as a source of food and shelter for animals. Pupils should compare animals in familiar habitats with animals found in less familiar habitats, for example, on the seashore, in woodland, in the ocean, in the rainforest. Pupils might work scientifically by: sorting and classifying things according to whether they are living, dead or were never alive, and recording their findings using charts. They should describe how they decided where to place things, exploring questions for example: 'Is a flame alive? Is a deciduous tree dead in winter?' and talk about ways of answering their questions. They could construct a simple food chain that includes humans (e.g. grass, cow, human). They could describe the conditions in different habitats and micro-habitats (under log, on stony path, under bushes) and find out how the conditions affect the number and type(s) of plants and animals that live there.
L KS2 Year 3	**Rocks** describe in simple terms how fossils are formed when things that have lived are trapped within rock	Pupils might work scientifically by: observing rocks, including those used in buildings and gravestones, and exploring how and why they might have changed over time; using a hand lens or microscope to help them to identify and classify rocks according to whether they have grains or crystals, and whether they have fossils in them. Pupils might research and discuss the different kinds of living things whose fossils are found in sedimentary rock and explore how fossils are formed.
UKS2 Year 6	**Evolution and inheritance** 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	**Evolution and inheritance** Building on what they learned about fossils in the topic on rocks in year 3, pupils should find out more about how living things on earth have changed over time. They should be introduced to the idea that characteristics are passed from parents to their offspring, for instance by considering different breeds of dogs, and what happens when, for example, labradors are crossed with poodles. They should also appreciate that variation in offspring over time can make animals more or less able to survive in particular environments,

	identify how animals and plants are adapted to suit their environment in different ways and that adaptation may lead to evolution.	for example, by exploring how giraffes' necks got longer, or the development of insulating fur on the arctic fox. Pupils might find out about the work of palaeontologists such as Mary Anning and about how Charles Darwin and Alfred Wallace developed their ideas on evolution. **Note:** At this stage, pupils are not expected to understand how genes and chromosomes work. Pupils might work scientifically by: observing and raising questions about local animals and how they are adapted to their environment; comparing how some living things are adapted to survive in extreme conditions, for example, cactuses, penguins and camels. They might analyse the advantages and disadvantages of specific adaptations, such as being on two feet rather than four, having a long or a short beak, having gills or lungs, tendrils on climbing plants, brightly coloured and scented flowers.

At KS3, Genetics chromosomes, DNA and genes

- heredity as the process by which genetic information is transmitted from one generation to the next
- a simple model of chromosomes, genes and DNA in heredity, including the part played by Watson, Crick, Wilkins and Franklin in the development of the DNA model
- differences between species
- the variation between individuals within a species being continuous or discontinuous, to include measurement and graphical representation of variation
- the variation between species and between individuals of the same species means some organisms compete more successfully, which can drive natural selection
- changes in the environment may leave individuals within a species, and some entire species, less well adapted to compete successfully and reproduce, which in turn may lead to extinction
- the importance of maintaining biodiversity and the use of gene banks to preserve hereditary material.

KS3 Earth and atmosphere

- the composition of the Earth
- the structure of the Earth
- the rock cycle and the formation of igneous, sedimentary and metamorphic rocks
- Earth as a source of limited resources and the efficacy of recycling
- the carbon cycle
- the composition of the atmosphere
- the production of carbon dioxide by human activity and the impact on climate.

KS 4 Ecosystems

- organisms are interdependent and are adapted to their environment

KS4 Evolution, inheritance and variation

- the genome as the entire genetic material of an organism
- how the genome, and its interaction with the environment, influence the development of the phenotype of an organism

- the potential impact of genomics on medicine
- most phenotypic features being the result of multiple, rather than single, genes
- single gene inheritance and single gene crosses with dominant and recessive phenotypes
- sex determination in humans
- genetic variation in populations of a species
- the process of natural selection leading to evolution
- the evidence for evolution
- developments in biology affecting classification
- the importance of selective breeding of plants and animals in agriculture
- the uses of modern biotechnology including gene technology; some of the practical and ethical considerations of modern biotechnology.

KS4 Earth and atmospheric science

- evidence for composition and evolution of the Earth's atmosphere since its formation
- evidence, and uncertainties in evidence, for additional anthropogenic causes of climate change
- potential effects of, and mitigation of, increased levels of carbon dioxide and methane on the Earth's climate
- common atmospheric pollutants: sulphur dioxide, oxides of nitrogen, particulates and their sources
- the Earth's water resources and obtaining potable water.

Appendix 2 Working Scientifically

KS1

- asking simple questions and recognising that they can be answered in different ways
- using their observations and ideas to suggest answers to questions
- gathering and recording data to help in answering questions.

Lower KS2

- asking relevant questions and using different types of scientific enquiries to answer them
- reporting on findings from enquiries, including oral and written explanations, displays or presentations of results and conclusions
- identifying differences, similarities or changes related to simple scientific ideas and processes
- using straightforward scientific evidence to answer questions or to support their findings.

Upper KS2

- planning different types of scientific enquiries to answer questions, including recognising and controlling variables where necessary
- using simple models to describe scientific ideas
- reporting and presenting findings from enquiries, including conclusions, causal relationships and explanations of results, in oral and written forms such as displays and other presentations
- identifying scientific evidence that has been used to support or refute ideas or arguments