Understanding of Evolution and Inheritance at KS1 and KS2: Report on feedback from KS3-KS4 biology teachers

Terry Russell and Linda McGuigan, Centre for Lifelong Learning, University of Liverpool.

This Report on feedback from KS3-KS4 biology teachers 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 full report and project summary, a review of literature and resources and formative assessment probes for classroom use. All of these are available at www.nuffieldfoundation.org/primary-pupils-understanding-evolution-and-inheritance

Introduction

Funded by the Nuffield Foundation, the authors undertook research with KS1-2 stakeholders into the implications of the introduction of Evolution and Inheritance in the National Curriculum. The classroom–based enquiry involved twelve teachers and their children drawn from KS1 and KS2 schools in Liverpool, Wirral, Warrington, Rochdale, Fylde, Lancashire, Blackburn with Darwen and Flintshire. The complexity of the subject matter necessitated clustering into manageable sub-domains, achieved by defining five themes that seemed to have conceptual coherence, yield workable packages for teachers and children, take into account available information regarding conceptual trajectories and offering sufficiently broad access for children of all capabilities across the 5-11 years age range.

Outcomes are reported in a series of articles that have appeared (or will appear) in the Association of Science Education's journal, Primary Science. Given the authors' concern with conceptual progression, an important aspect of the study was the desire to ensure that the teaching and learning at KS1 and 2 should support 'secondary readiness' and transition into KS3. In a brief follow-up study, KS3 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 and KS4.

In order to contextualise the KS3-4 teachers' comments, the themes, sub-domains and activities conducted by the KS1-2 sample are briefly summarised here.

Fossils

- Visiting museums and field trips to explore a wide range of fossils.
- Handling, observing and recording real fossils specimens.
- Making sequenced drawings to show ideas about how fossils were formed.
- Observing and recording clay mixtures to explore sedimentation.
- Making 3-D models to show the fossil may have looked as a living organism.
- 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.

Variation

- Observation and measurement of some of the physical differences between children such as hand span' or 'foot length'.
- Observation, counting and measurement of differences between the same species of plants found locally.
- Measurement of same kinds of fruit and vegetables such as apples.
- Observation, counting and measurement of the same species of animals such as tadpoles, stick insects etc..
- Recording measurement data in charts, graphs etc. and discussion to link patterns with distributions in populations.

Inheritance and Selective Breeding

- Discussion of resemblances between parents and offspring and how traits transmitted.
- Narrative stories such as 'Little changes ' and 'Wolves in the walls' to encourage expression of ideas about inheritance, domestication, selective breeding and adaptation.
- Constructing 2-D and 3-D designer pets to suggest ideas about inheritance over generations.
- Personal research to build an understanding of kinds of features that might be selected as preferred traits for selective breeding transmitted.
- Selective breeding for domestication, (meat, wool, vegetable) to encourage discussion of preferred traits and how transmitted.

Deep Time

- Using commercially produced wall charts to explore the sequencing and timing of evolutionary change.
- Creating sequenced drawings of the timing and sequencing of events to be used as claims for argumentation.
- Creating different scaled models of time such as 450-page book of important events, or a 45m or 450 m trail of significant events.
- Exploring ways of representing the magnitude of time such as 450 million years as numbers.

Evolution (from a macroscopic perspective)

- Narrative fiction stories to introduce ideas about evolution such as 'One smart fish'.
- Researching extinct and endangered species of animals and plants to develop knowledge and to help formulate claims for argumentation.
- Using real branches as a metaphor for Tree of Life to encourage learning about common descent and relationships between species.
- Making 2D and 3D cladogram models to show ideas about common descent, relationships between species and extinction.

The KS3-4 sample

The KS3-4 sample was drawn by invitation through social media and the newsletter of the Society of Biology as well as any teachers who had responded to the EiS 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 showed a high level of consistency and were consequently deemed to be offering a helpful and realistically accurate general picture of KS3-4 attitudes towards the salient aspects about which people were invited to offer comments.

All KS3-4 respondents were provided with the five articles that summarised the Nuffield funded Genetics and Evolution research as published in the ASE's journal, 'Primary Science' (Russell and McGuigan, 2014-15). A structured response sheet was provided inviting comments against the five themes: Fossils, Variation, Inheritance and Selective Breeding, Deep Time and Evolution (from a macroscopic perspective). This brief report is structured against reactions and responses to research and KS1-2 classroom activity relating to those five themes.

Theme 1 Fossils

1.1 In your view, how do these experiences prepare children for study at KS3?

All respondents were positive about all the reported KS2 activities except for one comment in relation to children's exploration and observation of sedimentation in jars. One KS3 teacher believed this activity would be unlikely to engage children's interest and would not be time-cost-effective. This might be the case at KS3, but the activity introduced important vocabulary through the terms 'sedimentary' and 'sedimentation' through action and observation. This was judged to be invaluable in the context of introducing the idea of sedimentary rocks and the possibility of organisms becoming embedded in what would later be seen as hard, solid rock. A more detailed description of approaches in KS1 and KS2 might have quelled these reservations. Children in Year 2 observed the settling of a clay suspension in bottles of water. One bottle was available for observation and another for children to handle and shake. Adding different suspensions to the bottle such as coloured chalk that formed different layers extended the activity. Some children added model dinosaurs. Children responded positively and their interest was sustained over a half term in which

they shook the bottles, discussed and recorded their observations. It was children's ideas to add dinosaurs to the mixtures suggesting that the link between the model and the embedding of fossils in different layers was being made. All but one of the respondents were positive about the practical experience of observing the sedimentation processes. The majority believed that an appreciation of fossil formation was a key understanding to be achieved at the end of kS2. Several suggested that this exploration could be extended so that depth of layer might be related to older occurrences
'… the idea of sedimentation as described by pupils putting sediments in a jar is good and could be modified so that it overtly links the idea of lower layer is oldest.'

It was generally recognised that the full range of activities described would be an unlikely provision in every feeder KS2 school. Typical of the feedback was the remark:
'I think the suggested experiences such as finding their own fossil specimens (where possible) and understanding the significance of fossils through using their imagination to produce 3D models or animations would help to prepare pupils and increase their enthusiasm.'

'The experiences suggested would more than adequately prepare students for study at KS3.'

'However, is seems unlikely that all primary schools will be able to offer such a rich and varied diet.'

There was no suggestion that content was missing from the experiences offered at KS2 but two respondents mentioned the importance of widening children's experience of fossils to include plants.

'An understanding of the existence of plant fossils (and possibly fossils from creatures that lived in the sea) is key – especially when students are asked to consider fossil fuels such as coal and oil at both KS3 and KS4.'

There was also a reminder of an important teaching point:
'Some teaching at KS2 may ask them to consider whether all rocks will contain fossils.'

1.2 Is there explicit reference to fossils and dinosaurs as evidence for evolution at KS3-4 that will offer continuity?

Although the research relating to Evolution and Inheritance was driven by the curriculum innovation at KS2, the researchers were aware that the prevalence and popularity of both fossils and dinosaurs starts with very much younger children, being nurtured by activities and models even amongst Early Years groups. It was of interest to discover whether these highly motivating conceptual areas were sustained and utilised at KS3. The picture presented is that, following secondary transition, dinosaurs as subject matter content slips under the radar of the formal educational agenda altogether. Fossils were reported to be within the scheme of work and therefore addressed at KS3 by about two-thirds of respondents, but several noted that fossils were by no means in a key conceptual position in the progression of the national curriculum. (This issue of continuity is further addressed below.)
One respondent explicitly showed recognition of the motivational aspect of the study of dinosaurs:
'The mysteriousness of the dinosaurs adds to the excitement, and tapping into this is a great place to start the difficult concepts of natural selection.'

1.3 What are the essential experiences about fossils that you expect from KS2?

The comments of about three-quarters of the respondents referred to the fact of fossils being an important source of **evidence** for evolution and the fact therefore that exposure to fossils should be a stimulus for thinking and **Working Scientifically**. As one response emphatically summarised this viewpoint: *'My only recommendation is that pupils understand that fossils provide us with information (evidence).'* A similar comment was:

'At KS2, I would like to see them handle some real fossils, explore pictures and stories of their discovery, see and study a timeline to get an idea of age, and make some model fossils to begin to understand the ways in which they can be formed, as well as discuss what they might tell us'.

Museum visits were mentioned with approval by about a third of teachers because they offer a different environment from school and are deemed to be memorable and relevant.
'Museum visits offer opportunities to children to experience science in a different environment and often in a much more interesting way'.

'Particularly useful are the "drawing back through time", "forming sediments" and "making 3D models of how the live organism looked" activities. These concentrate on how the fossils are formed and how scientists use fossils to reconstruct the organisms.'
These are the main points that I feel need to be covered:

- *Conditions have to be just right for fossils to develop. Only very few living things end up as fossils.* [a minority view]
- *How fossils are formed and the time it takes.* [almost unanimous agreement]
- *Preserved remains such as frozen mammoths and elk bones in peat are not the same as fossils. Fossils are rocks.* [About a fifth in agreement]
- *How our knowledge progresses with more evidence, for instance, the first reconstruction of iguanodon in the 1800's was found to be incorrect as more finds were discovered.'* [three-quarters in agreement]

Expectations of 'secondary readiness' in respect of fossils is perhaps summed up by this comment:
'To be aware of what fossilised remains are, how they are formed, to have some concept of the age of fossils and to have some understanding of the significance of fossils in terms of the evidence they provide of evolution.'

1.4 What recommendations would you make (what would you like to see happen between KS2 and KS3) to improve continuity and progression in the transition of this theme?

There was a range of specific recommendations. The minimum requirement seems to be that KS3 teachers would like pupils moving into Y7 to have at least an experience of fossils, to know what they are. Further considerations included the following ideas:

- CPD for teachers (and teacher trainers!) to support their understanding of the key ideas and help dispel some misconceptions.
- work back from fossil to consider causes of extinction and consider homologies
- use broader range of fossils than the most common examples
- perhaps more able children to be stretched by discussing how we might be able to compare or find the age of fossils by looking at the layer of rock they are found in
- Possibly to learn about the limitations of fossil records as well
- Maybe more opportunity for students to see fossils in real life (e.g. museum visits).
- It would be really helpful if students knew what fossils were and why they are important in terms of evidence for evolution.
- It would be helpful if students are aware that not all fossils are the same age. Also could they be aware that the fossilisation process itself takes a long time?
- broad range of fossils beyond mineralisation and awareness of absence of soft-bodied organisms in fossil record

Continuity and progression

As one respondent saw things, at 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.
'This would cause a gap in the continuity. I would recommend more time at KS3 to introduce and study evolution.'
The current lack of continuity in the consideration of fossils *per se* and as a source of evidence for evolution was noted by about a half of respondents:

'There is currently no explicit reference to fossils at KS3. At KS4 most recent guidance from the Department for Education (Feb '15) states:

'describe the evidence for evolution, including fossils and antibiotic resistance in bacteria'
This links fossils to the idea of evolution. In some exam boards, human evolution and human fossils are used.'
This point was elaborated in another response:
'I think the biggest problem is actually a gap at KS3 where fossils are not really taught in any detail if at all. There is no continuity at the moment from KS2 to KS4 which I think could be addressed… Pupils may start learning about fossils at KS2 and not pick it up again until the end of KS4. There is much more time spent focussing on reproduction, variation and inheritance at KS3 and much less on fossils and evolution.'
And again:
'There is no explicit reference to fossils and dinosaurs as evidence for evolution in the new KS3 science curriculum. Therefore, it may be difficult to offer continuity. Individual schemes of work, as written by individual schools/companies may touch on the topic as a way of delivering the curriculum but I am unable to comment on these having not seen any'.

Theme 2 Variation

2.1 In your view, how do these experiences prepare children for study at KS3?

There are two main aspects to report under this theme: that of Working Scientifically that includes thinking about patterns in data and constructing graphs to represent normal distributions; secondly, the conceptual aspects of essentialist thinking. The latter was challenged by the empirical exploration of differences in within-species attributes that were otherwise likely to be considered uniform or identical in nature.

Activities as supporting secondary readiness

All respondents confirmed that the ideas and activities presented would be welcomed as KS1-2 precursors of KS3-4 study, particularly in the manner of '*focussing on working scientifically …and developing mathematics and literacy*' at the same time.
'an excellent range of activities. These encourage analytical and data handling skills that are inherent to all of science not just the topic of variation. All of these would be very useful.'
'These experiences are an excellent preparation for study at KS3. In fact, if this is the norm, our students are arriving better prepared than I ever realised.'

In fact, we do not claim the reported KS1-2 activities to be the norm. They were generated by researchers and teachers collaboratively with funded time to consider, act and reflect. What can be asserted is that all activities were in some manner within the scope and capabilities of teachers and children throughout the KS1-2 range.

The value of Working Scientifically

The realisation that KS1-2 children were thinking about the data their teachers encouraged them to collect was appreciated, as well as the observation, measuring and recording aspects of the tasks.
'*These experiences of measuring, recording and presenting data will prepare students well for KS4. It is fascinating that some students were beginning to think about why this variation occurred.*'
'What is important at the KS3/4 level is the level of understanding. Why is the distribution like this? What does it mean? When linked to the controlling factor being environmental, genetic or both having the influence and which one leads to greater distribution. Again these activities do provide the opportunity to collect data in relevant tables, and present in suitable graphical format.'

Attending to continuous and discontinuous differences in data

'I think the listed activities would prepare pupils well. At KS3 we often focus on measuring physical features of children and plotting histograms and graphs with the data…. At KS3 we start to move on and discuss the possible causes of the variation within a species (either inherited, environmental or both). I think pupils at KS2 could start looking at continuous and discontinuous variation in preparation for KS3.'

Our KS1-2 research did not treat continuous and discontinuous variation as twin possibilities or alternatives. Rather, each kind of variable (continuous or discontinuous) was examined separately. Continuous variables were examined within our Variation theme while discontinuous variables were integral to the Selective Breeding and Inheritance theme.

Within-species variation

'The experiences listed and written about would provide children with an excellent grounding for studying variation at KS3… in my experience of teaching the topic to Year 8 pupils, they frequently quote differences among humans (e.g. skin colour, hair colour, eye colour) but rarely consider the differences between members.'

'The list of activities covers all of the key ideas that we would hope to see KS2 students bring with them. It is important that they have had time to think about many of the ways in which living things differ.'

'Variation (leading to adaptation) is a huge factor when considering the vast idea of natural selection by a process of evolution.'

'These experiences are crucial to pupils understanding of variation. However I do feel that some of the activities we complete at key stage 3.'

Personal ownership of data

One small aspect that emerged relevant to differences in attitudes towards motivating primary versus secondary students was the suggestion by one respondent that whereas at KS2, children had well-defined personal ownership of e.g. the seedlings that had been grown, the personal ownership of the plants was not regarded as important at KS3 – and might be discouraged. Admittedly, personal ownership introduced a competitive element to the ranking of plants by height, but in a typical KS2 ethos, the motivational aspect was valued. The competitive aspect could also be used to introduce the potential for introducing bias to what should be a neutral observational activity. We cannot claim this latter aspect was exploited. Rather, the challenge to any such perceived pupil distortion in the data (such as a desire to own the plant with the largest number of leaves, or to have grown the tallest plant) was more likely to be framed by teachers as a requirement to look again and ensure 'fair' treatment in the ranking.

2.2 Is the link between mathematics and evolution recognised and developed in KS3-4?

Our research was interested to explore the relationship between the well-established phenomenon of essentialist thinking in young children and possibilities of challenging such beliefs through straightforward observational activities. In particular our interest was in a) children making

measurements, an activity that would highlight differences and b) drawing graphs that would reveal normally distributed data. In this ambition, teachers and (even surprisingly young) children were successful, resulting in interpretations of 'hill-shaped' patterns. This was the motive in enquiring about the use of mathematical tools in supporting ideas about evolution – specifically, the normal distribution of continuous measurement data. The question as posed was broader in nature, requiring respondents to consider links between mathematics and evolution in any manner they considered to be relevant. Responses were, as a consequence, framed in specific as well as more general terms. (We were also aware of the current relevance of the issue of integration of maths in science at KS3 and KS4 and attempts by science subject organisations and awarding bodies to promote integration and to develop guidance materials. For further information see http://www.ase.org.uk/resources/maths-in-science/.) Two thirds of the respondents described their teaching of evolution as including links with mathematics. About one half of respondents mentioned the fact that students were required to draw graphs and to consider normal distributions in data. More generally, and taking a wider view, three quarters of respondents indicated the lack of links between maths and science and a quarter expressed a strong desire to grasp the opportunity to forge links between the two subjects. An interestingly topical aspect of this or our data is illuminated by the observation that:

'Your identification of explicit links comes at a good time as the mathematical demand of mathematics in science at KS3 and 4 is ramped up'.

'A quick look at GCSE Mathematics guidance from the Department for Education (2013) reveals the following:

understand that empirical unbiased samples tend towards theoretical probability distributions, with increasing sample size.
And:
construct and interpret diagrams for grouped discrete data and continuous data, i.e. histograms with equal and unequal class intervals and cumulative frequency graphs, and know their appropriate use.
Also
Interpret, analyse and compare the distributions of data sets from univariate empirical distributions through:
- appropriate graphical representation involving discrete, continuous and grouped data, including box plots
- appropriate measures of central tendency (median, mean, mode and modal class) and spread (range, including consideration of outliers, quartiles and inter-quartile range).
And finally:
-apply statistics to describe a population.
'I would have to confer with Mathematics colleagues to understand how these aspects in the curriculum would be taught, however I would imagine that this refers to the normal distribution. There should be a greater overlap between variation and population studies in Biology and interpreting statistics in Mathematics.'

While the potential links are clear enough in the above quotations from the mathematics curriculum, on the ground, specific links either with the conceptual understanding of evolution or with mathematics departments are less certain.

'Explicit development, no; links with mathematics department – rarely.'

'It isn't, sadly, as it would make teaching variation within a population more sophisticated and perhaps more engaging for students at KS4.'

'A strong emphasis is made on developing skills learned in maths lessons when teaching variation at KS3 & 4. In particular: recording data, data handling, plotting and interpreting graphs and using spread sheets. Pupils often have to be reminded that drawing graphs etc. in science lessons are no different to graphs in maths lessons, as they often see these as two very distinct subjects.'

'Commonly at KS3 we will discuss variation, but only between humans. We will also focus on environmental and genetic variation. Typically, we have never discussed what a normal distribution is - I'm really interested to see that this is being done in primary school.'

Possibly there exists an under-estimate of the measuring and graphing carried out in primary schools. Certainly, it is KS2 experience and activity that is valued at KS3.

'… at KS3 the link between mathematics and evolution would definitely be recognised and developed further. Currently at KS4, there is no requirement to integrate mathematics with the study of evolution at all and interestingly there was no mention of it in the draft of the new KS4 curriculum. However, it is important to note that the focus on numeracy across the curriculum is only increasing and opportunities to develop numeracy in science should be grasped regardless of whether or not they are stated on the curriculum specifically.'

(This requirement does not encompass mathematical tools such a plotting normal distribution (or getting pupils into lines for continuous or groups for discontinuous attributes, as another respondent describes their practice.)

'*Unfortunately not – at least not in our school as yet. We are doing work similar to that described in your article at KS3 - we look at variation and distributions, comparing environmental and genetic variation. Data are handled appropriately within science lessons but there is little cross-curricular work with the Maths dept. Such collaborations would be highly valuable – and as a department we are aware of this!*'

'*Yes, however a lot of the things you are doing in primary such as hand span measuring and apple circumference measuring are also done at secondary. This is an area that even if covered at primary tends to need consolidation. At KS3 more precise graph drawing skills are covered and sample size is discussed.'*

'*Absolutely, beginning with the over-production of offspring linked to probability of survival for some species, then continuing with species that 'care' for their offspring producing fewer numbers. Altruism and the selfish gene - survival of a species by the inherent and innate desire to pass on our genes leads to another idea considered at KS4 which links to percentages of our genome that are passed on to future generations. Lastly, the normal distribution is a key idea that we teach for continuous variation and interpreting of normal distribution graphs is a key skill required for exam success.*

An explicit reference to plotting and describing normal distributions relating to within-species variation seems not to be a widespread strategy in KS3 biology teaching and learning. More often, it was the more general aspects of links with mathematical thinking that were recognised:

'*Any opportunity to combine maths with science must be embraced! Too many children compartmentalise different subjects, asking 'why are we doing maths in science?' when asked to handle data or produce graphs. Introducing these key mathematical tools at KS2 would be very beneficial as these are tools needed throughout the KS3 & 4 science syllabus and beyond. This should be tied in with all aspects of science, not just evolution, from as early as possible.'*

Reference to drawing attention to the normal distribution curve was not totally absent.

'I also like to make the link with the normal distribution curve although I think it very much depends on the scheme of work being used as to how much emphasis is placed on this. With the new KS4 curriculum though there may be more links made with mathematics.'

2.3 What recommendations would you make (what would you like to see happen between KS2 and KS3) to improve continuity and progression in the transition of this theme?

One recommendation was to make professional development activities available for teachers.

A greater emphasis on the distinction between continuous and discontinuous within-species variation at KS3 was seen as a development from the activities described at KS2. Two fifths of respondents mentioned the importance of preparing children to be able to distinguish discontinuous and continuous data at KS3 with one fifth suggesting the distinction should be explicitly introduced at KS2. In the younger age group, both forms of variation were discussed at different times, but not in contradistinction.

'I would suggest further work could be done looking at highlighting the difference between continuous and discontinuous variation. After completing the activities suggested, get pupils to organise themselves into groups depending on their eye colour ask them how this if different to collecting data about heights for example. One simple think I have done is got the pupils to line up in height order to get the idea of pupils being able to take a value on a scale. I then get the pupils into groups of eye colour and ask the pupils what the difference is. Most get the idea that pupils are now stood in groups rather than in a line. I see no reason why this couldn't work well at KS2 and would definitely set the pupils up well for further study at KS3.'

There is certainly an issue of sensitivity of which primary teachers are well aware, being careful to avoid any discussions that might impinge on intra-familial genetic history.

'I can understand why discontinuous variation may be left out at this stage (concerns over students recognising that they differ in terms of eyes, skin, hair), but it could be taught through use of different breeds of animals like rabbits, horses or dogs or through different coloured flowers. Being able to recognise whether variation is discontinuous or continuous is a necessary skill at KS4.

Macroscopic and microscopic perspectives on variation

*One fifth of respondents suggested that some prior knowledge of genes, DNA and chromosomes etc at KS2 might well be useful preparation for KS3 study. 'In the resources, it is stated that students do not cover the microscopic elements of this topic at KS2. Previously, I would not have cited this as an issue. However, the new KS3 curriculum wants students to understand "**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 mode**l". Whilst I completely appreciate that it may not be appropriate for students to have been exposed to this in detail before KS3, it would be beneficial to us at secondary school if they did have some prior understanding of the basics.'*

It was noticed in passing in the course of the KS2 research activity that some pupils – not a majority – brought up the subjects of gens and DNA. This was not instigated by teachers but was a matter of pupils drawing on personally acquired knowledge. The incidence and its relevance to the discussions in which children were involved were sufficient for us to consider the possibility of exploring the extent of such understanding in a more systematic programme of research.

'It would be very useful for pupils to be taught about the causes of variation and to make links between genetic material when learning about basic cell structures. Discussions such as those about Dolly the Sheep often come up in KS3 (although cloning is not specifically taught) and certainly in KS4 where it is part of the teaching material. I have a poster of Dolly the sheep in my classroom and so

many pupils at KS3 are incredibly curious about the concept of cloning. This often leads nicely to discussions about DNA and the nucleus, which KS3 pupils often have many misconceptions about. Therefore to place more emphasis on what can cause variation in any species is, I feel, a way to improve progression from KS2 to 3.'

'It is possible that discontinuous variation can also be sensitively discussed i.e. non-measurable variation such as eye colour, shoe size, hair colour, which is different from continuous and does not necessarily produce a normal distribution shape of a bar graph. Also that variation (whether discontinuous or continuous) will not always confer a selective advantage to the organism but may also be deleterious or neutral, both important in natural selection.'

Theme 3 Inheritance and selective breeding

3.1 In your view, how do these experiences prepare children for study at KS3?

The 'official' position at KS3-4 is defined by the Department of Education, 2013 specification (in bold font below), the requirement being to cover:

Heredity as the process by which genetic information is transmitted from one generation to the next.
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.
The range of activities explored in the course of the KS1-2 research was entirely approved by all respondents as supporting 'secondary readiness'.

'Pupils who have been involved in these activities and learned from them will be more than what is currently considered to be secondary ready.'
'Once again, great ideas for youngsters' development in a wide range of concepts and skills. I very much liked: reverse engineer a parent; models of parents and offspring; assistance dog.'

Heritability and sexual reproduction

Something the KS1-2 research and classroom activities did not explore was the role of sexual reproduction in heritability, other than assuming that, for example, male and female dogs would breed (or 'be bred') to produce young. Some comments from one fifth of respondents to the KS3 invitation to feedback made it clear that the increasing shift towards a molecular description of processes would be likely to incorporate information about sexual reproduction, possibly including human sexual reproduction. A recent parliamentary briefing paper clarifies requirements www.parliament.**uk**/briefing-papers/SN06103.pdf (our bold):

1.12 The Department recommends that all primary schools should have a sex and relationship education programme tailored to the age and the physical and emotional maturity of the children. It should ensure that both boys and girls know about puberty and how a baby is born – as set out in Key Stages 1 and 2 of the National Science Curriculum.

While the science national curriculum aspects relating to sex and relationship education are compulsory, parents are free to withdraw their children from all other parts if they choose to do so.

Of course, sexual reproduction is the very mechanism that produces variation in offspring, so not surprisingly, from KS3-4 teachers, feedback included:

'Area to investigate: Where does all this fit with the teaching of sexual reproduction? Some of the ideas, e.g. heritability of acquired characteristics, might require carefully supported teacher guidance.'

'Ideas of inheritance can be very abstract until children have a firm grasp of sexual reproduction which is not taught until years 5/6, so tackling this is very difficult.'

'An activity I felt was interesting was taking the offspring and deciding what the parents could look like, rather than deciding what the offspring could look like.'

Selective breeding approach approved

Selective breeding as an accessible means of entry to the broader picture of species evolution was appreciated as a useful approach, with the caveat offered by just one respondent that care should be taken over potential confusions as to the definition of 'species'. This is something to emphasise to teachers – and something that was not highlighted in the KS2 work. Species definition raises the question as to the point at which drift into separate populations gives rise to sub-species and then species that are not capable of inter-breeding.

'Dog breeding is an excellent example to use but at Key Stage 4 crops seem to mentioned more often. It might be an idea to introduce both dogs and crops.'

'…a wide range of activities to engage the children and get them thinking and discussing. This area of study also has opportunities for cross-curriculum studies into social history. Care must be taken at this stage, however, when studying dogs and other domestic animals to emphasise that breeds are not the same as species as this confusion can be witnessed at KS3 & 4. The difference must be identified to dispel misconception and promote clearer understanding.'

The positives drawn from the selective breeding orientation were focused on the accessibility of the subject matter that was drawn upon and its familiarity in the context of children's everyday lives. However, currently the situation would appear to be such that continuity with work at KS3 would require modifications to the curriculum.

'I think that the activities on selective breeding are engaging and valuable, especially when pupils are moving to schools where this is taught in more detail at KS3. Having said this there is no mention of selective breeding specifically in the most recent KS3 curriculum and more emphasis should probably be placed on this. It is an interesting area of study and provides opportunities for pupils to make real world links and consider the economic and ethical issues farmers/food produces have to consider when selecting animals and plants they wish to reproduce.'

'I think these experiences would be very useful to prepare for transition to KS3 and preparing for KS4. I have found that pupils' prior knowledge of Inheritance and selective breeding is often lacking. Using examples of animals like guide dogs would be especially beneficial to make selective breeding more relevant to real life situations.'

'The experiences are sound for allowing children to understand the basic idea of heredity. The students will gain a better understanding of the fact that characteristics are inherited from parents. There is a lot of focus on selective breeding [in the reported KS1-2 work]*, which doesn't feature on the curriculum until KS4. However, this is still useful as a vehicle for explaining why offspring are similar but different to their parents and how to breed useful characteristics. It is also important that students are exposed to ideas about selective breeding prior to KS4.'*

The role of narrative fiction

The role of fictional frameworks to initiate and structure dialogic processes was not a focus of the feedback, but was commented upon by two-fifths of respondents:

'Using stories to teach pupils about inheritance and for them to then create their own stories might be beneficial for consolidating knowledge and could be something they draw on in KS3 study.'

'I really like the idea of using stories to help engage younger pupils and allow them to start understanding the process of evolution. I think the main idea pupils need to bring with them to KS3 is that changes happen in populations over a long period of time and I think the story suggested would help with this.'

This is an area of particular interest to the authors that has received some attention elsewhere (Avraamidou & Osborne, 2009) but which tends to polarise opinions amongst science teachers.

Further KS2 research suggested

Another perspective was the suggestion of introducing the word 'gene' as a unit of inheritance mentioned by a quarter of respondents. *'This would help to prevent the misconception associated with the misuse of 'DNA' to represent the inheritance of characteristics from parents to offspring.'* *'If the term DNA is being mentioned by students due to media, then why not explore this in a little more detail at KS2 level. More able students could actually be appreciative of knowing the concept of chromosomes and genes to understand where this DNA comes from.'*

3.2 What recommendations would you make (what would you like to see happen between KS2 and KS3) to improve continuity and progression in the transition of this theme?

Fertile content for 'argumentation'

The macroscopic approach to evolution by reference to selective breeding received general approval, especially in the opportunities it offers for dialogic interaction and 'argumentation' as an instance of Working Scientifically. One quarter of the sample of KS3 respondents suggested selective breeding offered productive opportunities for the development of argumentation skills.
'It may well be that year 6 students are not yet mature enough to consider the ethics of selective breeding but perhaps an introduction to the idea of scientific argument may be possible.'

'What is discussed here would provide a good foundation for students to then progress onto the discussion of morality in the selective breeding of plants and animals when they are more mature in KS3.'
Although the KS3-4 reaction to the selective breeding approach was generally positive, it was also suggested that the natural selection processes of evolution should be introduced to older primary pupils, with environmental factors identified as the pressure on selection (rather than human control of breeding) being clearly introduced.

'I think I would like to introduce the idea of natural selection to pupils toward the end of KS2. I would keep things really basic but I think it would start to introduce the idea that changes occur to the individuals in a population across generations when the environment changes.'

'*This* [topic of selective breeding] *is an area fully covered at KS4 but again is scanty or non-existent at KS3! This leads to the need to include this at KS3 to maintain continuity.'*

Animal husbandry to genetic engineering

Although a quarter of respondents reported teaching selective breeding at KS3, about a half of respondents 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. Selective breeding appears not to be on the agenda at KS3, despite acknowledgement of its social importance and historical relevance for human social and cultural development. It may be that the advances in technology, including genetic engineering, have displaced the simpler animal and plant husbandry of yore. The biological mechanisms are more complicated, requiring a microscopic or molecular framework that is reflected in changes to the KS3 approach.

'As there is now a much heavier emphasis on the molecular level of these processes at KS3, some introduction of this [process of selective breeding] *at this stage, however basic, would prove useful for this transition.'*

Theme 4 Deep Time

4.1 In your view, how do these experiences prepare children for study at KS3?

Our focus on children's conceptions of time in the KS1-2 research was part of the broad strategy of deconstructing the topic of Evolution and Inheritance into its foundational conceptual requirements. This approach seemed particularly innovative in the context of deep time and it seems likely that there is a more general adult uncertainty beyond the school population both about the scale of time and the definitions of the very large numbers used to measure it. Certainly, three quarters of KS3 colleagues responding to the invitation to feedback 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 our 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. Deep time is frequently linked to the history of the universe at KS3-4, but there appears to be little in the way of crossover links with evolution across the sample as a whole.

'Any development of a sense of number and scale can only be helpful across may areas of the secondary curriculum – humanities, maths, science, etc.'
'Students often have to create 'timelines' in study, for example in the development of the periodic table or the discovery of DNA.'

'All of these experiences would help prepare students for KS3. The idea of deep time is a difficult one to comprehend… I really like the concept of creating a 250-page book and students adding important moments in time to them.'

'The sequenced drawing activity and the timeline modelling activity really help children to visualise this and are used in KS3 & 4.'
'*Having recently seen some of the commercially produced time line wall charts that are available on display at the Big Bang Science Fair I would be very much in favour of these being used as a reference point for pupils in preparation for KS3. To see something like this on a daily basis would help to give them a sense of familiarity with a difficult-to-grasp concept.*

'Modelling timelines in physical walks around the school grounds or in the classroom I think would be very beneficial to help pupils develop ideas of scale.'

'This is excellent preparatory work for KS3. It is too often that we don't understand the prior knowledge that our students come to us with. The activities and experiences mentioned are very similar to those that we would use at my school during years 7-8, and probably will use now that there is more of an emphasis on evolution in the curriculum. So often, visual representations of these abstract concepts are what really help students to understand. If covered at KS2 and repeated at KS3, these kinds of tasks can prove to be really useful in cementing understanding.

Absolute and relative dating procedures

The sedimentation experiences were a tentative introduction to the notion of correlating depth of layer with age. There was no attempt to introduce radiometrics or carbon dating at KS1-2, though as one teacher suggested, it would be an interesting challenge to identify a means of doing so in a simplified yet comprehensible manner that does some justice to the science.

'Again the ideas presented are helpful and provide opportunities for consideration of evolutionary time. Is it possible to introduce ideas about how such long time periods are measured? For example how do scientists know the ages of rocks? Simple ideas about estimating age of ancient artefacts may be helpful.'

4.2 What references to the scale of deep or evolutionary time are used in KS3-4?

Responses from the secondary phase of education led to an indication that the role of deep time in the context of evolution may be a curious and important omission in many KS3-4 schools. Two thirds of the small sample reported that deep time is not explicitly included in the KS3 science national curriculum.

'I don't think there are any explicit references. I was surprised when I searched the KS3 PoS and GCSE subject content.'

'According to the KS3 Specification (Department of Education, 2013), there appears to be no reference currently to deep or evolutionary time at KS3. According to the latest available guidance for KS4 (Department for Education 2014), the idea of deep time can be used across the syllabus, for example when discussing evidence for evolution, the development of the Earth's atmosphere and the formation of the solar system and life on Earth.'

'We don't currently reference evolutionary time at KS3. However at KS4 pupils do study evolutionary time. I have completed very similar activities to the ones discussed with year 10 and they struggle with the concept.'

Deep time in other contexts

The recognition that pupils are likely to parcel up and compartmentalise their curricular experiences needs to be borne in mind when interpreting two thirds of KS3-4 teachers' responses, where the claim is that deep time is dealt with in other areas of the curriculum than in the context of evolution of life forms. *'Deep time is covered thoroughly in KS3 in the study of geology and the rock cycle. This is built on in KS4 in the study of the solar system and the Earth's formation, Hutton and Wegener, and the theory of plate tectonics. Deep time in relation to evolution is not really discussed until KS4.'*

'When teaching natural selection and evolution at both KS3 (year 8) and KS4 (year 10) pupils are expected to be able to describe how organisms evolve over time and to be able to relate this back to fossil records as examples of evidence from millions of years ago. There are more detailed references to human evolution for pupils who choose to study Further Additional Science (Edexcel) in KS4.'

'In the OCR 21st Century science syllabus at present students study life cycles of stars and the age of the universe. This is linked to evidence for the big bang. To help support this study reference is made to timelines where a year is divided into 12 months and key events are posted along this timeline.'

'KS3 and KS4 both have a study of space and the big bang theory, as well as the life cycle of stars and early Earth.

However, there are exceptions that utilize available visual aids:

We teach evolution at both KS3 and KS4, and I often use an idea from Richard Dawkins 'The Magic of Reality' where the students conduct thought experiments. These involve imagining a photo of themselves on top of a pile of photos 40 miles long.'

4.3 What recommendations would you make (what would you like to see happen between KS2 and KS3) to improve continuity and progression in the transition of this theme?

While there is a possibility (a strong probability, even) that in many schools neither evolution nor deep time will be mentioned at KS3, there was very broad acceptance expressed by three quarters of respondents of the necessity of dealing with the issue of scale in teaching science to all age groups.

'It is very easy to refer to time periods flippantly and for pupils not to have any grasp of the kind of scale involved, for example I have found pupils who can't see any difference between 'thousands of years ago' and 'millions of years ago' in terms of evolutionary history of the planet. It would therefore be beneficial to the transition from KS2 for pupils to have a better understanding of deep time and more concept of time periods throughout the Earth's history.'

'The idea of deep time is difficult for many students to grasp and indeed many of our KS4 students struggle with it. We have considered links with the history department but the GCSE syllabuses do not always allow for collaborative teaching. Perhaps trying to link history projects to evolutionary time at KS2 may be helpful?

' Deep time is so abstract and I think if students come with the mathematical and spatial bandwidth to start to visualise this, there is more we could do at KS3 rather than KS2. Indeed, we could re -cycle the idea when teaching early Earth!'

'I think the idea needs to be revisited at each key stage. I do particularly like the wall chart and have one up on my classroom wall. Pupils of all ages are fascinated.'

Theme 5 Evolution

5.1 In your view, how do these experiences prepare children for study at KS3?

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.

'They are invaluable. These ideas must be explored further and developed into teaching resources. I doubt that this depth is considered by many teachers at KS3, let alone KS2.'

'One of the things I found interesting about this unit was the comparison between the 'the ascent of man' image and the 'tree of life' and the way in which it encouraged the students to challenge misconceptions. In KS3, evolutionary thinking appears quite simplistic; students are required to understand that variation may confer an advantage on individual members of a species that then pass this characteristic to their offspring. This [KS1-2 research] *activity offers a more sophisticated view of evolution.'*

'I believe students being able to make their own 2-D and 3-D models would help them relate to the tree of life model and move away from that common misconception of linear Evolution.'

'I also think for pupils to start understanding the tree of life metaphor and cladograms will help them going into KS4 as I have seen a number of exam questions on the evolution topic using these. I think that their use a KS3 is likely to be mixed and as yet I have not taught using either of these at KS3.'

'…a useful range of activities. Sequenced drawings and modelling of cladograms being particularly useful in helping the children visualise and understand these concepts.'

It is possible that at KS3, the **mechanism** takes precedence over the big picture or macroscopic **overview** of evolution.

'I feel that more emphasis should be made on natural selection and evolution at KS3 in order to give pupils a consistent message through from primary school to GCSE exams where they are required to know about this in great detail.'
'These activities are excellent for preparing students for KS3. Typically, when these diagrams are studied at secondary school, we use simplified paper diagrams. The opportunity to handle them in a 3-D context will really bring the idea to life.'
'I love the branches of life using actual tree branches (non-withstanding the few students who thought the discussion was about plants!) to model that some branches are longer and some end, building on the ideas introduced about deep time, adaptation and survival in the face of competition.'

'These experiences are probably one of the most important. Pupils have this misunderstanding that humans come from apes. I believe the earlier this is addressed the better.'

5.2 Is the 'Tree of Life' metaphor used in Y7 and beyond, or if not, is there a case for doing so?

The Tree of Life as a scaffold for a macroscopic appreciation of evolutionary changes over time is innovative at KS1-2. At KS3, two thirds declared that students were not introduced to either the Tree of Life or to cladograms. This graphical manner of representing the 'big picture' seems not to be in common usage at KS3 and an appreciation of its affordances, constraints and possibilities for transliterations is therefore not widespread in supporting progression. Exposure to the reported KS1-2 research might have the effect of changing practice in later school years. All of the KS3 respondents indicated that they believed that KS3 students should be introduced to the metaphor of the Tree of Life and to cladograms.

'It is in some classrooms. Not consistent - e.g. It does not appear in all published KS3 schemes.'

'Many science classrooms have the classic posters in showing the tree of life, including mine!'

'Yes, the tree of life metaphor is referred to…. Certain sections of this could be looked at in closer detail using other secondary sources. In particular, the evolution of modern humans. This is where most confusion stems, because students believed there was an all of a sudden change from ape to man.

'We don't current use the 'Tree of Life' metaphor; I do believe there is case for doing this.'

'So far, the 'Tree of Life' is not used in Year 7 and beyond. From reading the article, I would like to add it to the KS3 Scheme of Work for evolution. I feel that using the 'Tree of Life' to describe evolution will help students' understanding at KS4. Students will be able to relate evolution to the vast amount of different species that exist.'

'I have not seen the metaphor used explicitly in KS3 science, but reading the material on how it can be used and its proposed benefits, I believe there would be a case for doing so and would be keen to adapt my own practice to incorporate this.'

'I have not used the 'Tree of Life' metaphor at KS3 but I have used it at KS4…. using all the images together allows pupils to understand the advantages and disadvantages of each one.'

'The Tree of Life is used well at KS4, not so much at KS3 in most schemes of work. It is a useful tool and its use should be encouraged.'

The linkage of cladograms and tree of life was not something that any of the KS3-4 responses identified as having a precedent at KS3-4. The tree of life and cladogram are not seen as complementary, which is precisely the virtue of dealing with them together. The cladogram has the potential for scale and measurement; the Tree of Life is more graphic and conceptually a visual

indication of relationships over time. There was perhaps not a widespread appreciation of the value to pupils in the different representational formats being used in combination.

'The tree of life metaphor is not currently used by my school in a formal sense. We incorporated it into 'enrichment lessons' as part of our old KS3 curriculum and it was enjoyed by students. They showed us that it is a valuable tool in helping to understand the mechanism of evolution - especially when accompanied by video resources such as David Attenborough. We will definitely be looking at incorporating it into our schemes of work when we design the year 8 section of our new scheme of work as part of the new curriculum. At KS4, the 'tree of life' metaphor is largely abandoned in favour of the cladogram.'

'So far in our GCSEs specifications no reference has been made and to my knowledge no teaching staff are using this as a teaching resource. However cladograms are used but not extensively – they are used primarily to consider evolution of humans from apes; study of other evolutionary changes by considering cladograms would be supportive here.'

'It is not used, at least not in my experience. The case for using it could be that it helps give a view of deep time; also it can help pupils to understand cladograms?? Especially if done as per the teacher who used the 'real' tree/small branch example.'

5.3 What are your thoughts about the introduction of cladograms at KS2 and KS3?

There was a view expressed implying that cladograms were regarded as 'tough', though in the KS1-2 activities, the point was to explore how different representational formats could be used in combination to ease access to an important and foundational idea. The notations included the visual Tree of Life; handling and interpreting the metaphor by reference to an actual physical branch; interpreting a 2-D cladogram and making a 3-D version of the cladogram.

When the possibility of introducing cladograms at KS2 was originally mooted, the context was a mixed group of KS1-4 teachers and it was pointed out that this format is not in general use until KS4. In this light, our interest was in KS3-4 teachers' views on introducing cladograms much earlier, perhaps at the upper end of KS2. There was partial evidence for the accessibility of cladograms with younger children (Ainsworth, 2013), but in research limited to their understanding of the internal logic of the diagrams, stopping short of their potential in helping pupils to establish appreciation of the 'big picture' of evolutionary changes over time. Three quarters of KS3 respondents welcomed the introduction of cladograms and Tree of Life to KS2 pupils. One or two felt that their introduction should be restricted to higher achievers or year 6 while all others expressed the sentiment 'the earlier the better'.

'Year 6 at the earliest. As models go, it's tough! What are the children really understanding and how might we assess it?'

'Cladograms have been used in GCSE exam questions, therefore their use at KS2 and KS3 will only strengthen ideas surrounding evolution.'

'*I believe cladograms to be very useful (more so with higher ability students, especially at KS3).'*

'To my knowledge, cladograms are not used at KS3…. I see no harm in introducing these at an early age and they will help to support pupils at KS4 when pupils will need to interpret these for their GCSE exams.'

'Cladograms are a very useful tool and should be introduced as early as possible.'

'I feel that cladograms would be beneficial if used at KS2 and 3 as pupils in KS4 often have a very narrow, linear view of evolution and are not aware of common ancestors of different species.'

'In my opinion, the cladogram is a little too easy for KS4 study. All students seem to grasp the concept of the cladogram readily and with ease. It is a topic that could easily be covered at KS3. A basic

introduction to these at KS2 would prove nothing but beneficial, especially if backed up with slightly easier concepts such as the tree of life metaphor.'

'I have used cladograms both at KS3 and KS4, and think that some experience of them before-hand could allow pupils to follow them more confidently.'

'I think they are simple and powerful enough to be introduced at KS2, and their value in negating misconceptions cannot be overlooked. We teach about evolutionary relationships at the DNA level, and how Gorillas and Chimps are 99% similar to us - this builds on the ideas of inter- and intra-relationships that are introduced using cladograms.'

'I believe most cladograms are an effective way to teach evolution and therefore should introduce at key stage 2.

5.4 What recommendations would you make (what would you like to see happen between KS2 and KS3) to improve continuity and progression in the transition of this theme?

While framed in a variety of ways, the essential message emerging was of a recognition that currently, curricular experiences between KS2 and KS3-4 tend not to support continuity and progression in pupils' engagement with ideas about evolution. For continuity to be a possibility, a coherent programme based upon a systemic overview would be necessary. The facile response is to suggest that teachers and their schemes of work must provide such a strategic overview. Our argument would be that Evolution and Inheritance are such foundational ideas in biology education that explicit strategic thinking is essential.

'A clearly considered strategy…. is definitely needed!'
There also seemed to be a feeling that at KS2, environmental factors have been insufficiently attended to or developed. This could well be true, as we chose instead to emphasis selective breeding as a more accessible route to understanding changes over time, where the 'environmental pressure' is human control of breeding possibilities. This approach would need to complement discussion of environmental pressures. One way of drawing pupils' attention to environmental factors is to refer to specific organism-environment interactions, as for example, the arctic fox, as referred to in the KS2 statutory guidance.

'Would it be possible here to relate variation and changes in environment to evolution? I'm thinking here of Darwin's finches. It would help tie this theme in with the others.'

'At KS4 some schemes make mention of evolution in action e.g. the evolution of the head louse to be resistant to some louse shampoos. Is it worth bringing these ideas in earlier or could it lead to confusion in terms of time scales overall??'
It was pointed out by two respondents that the distinction between species and 'breed' or 'variety' needs careful exposition when moving between ideas of natural selection and selective breeding:
'In the children's' quotes in the articles, they often refer to 'species', and I wonder how deep their understanding is of this term? Often at KS3 it is apparent that students do not really know the true definition of a species. I believe it would be of benefit to investigate this as it underpins a lot of the true understanding of evolution, selective breeding, and the cladograms.'

'The activities you have suggested seem to comprehensively cover the main areas I would expect at KS2. I think there is work for us to do as secondary teachers to ensure pupils progress their knowledge in this area at KS3 in readiness for KS4.'

'Again, we are looking at a gap in the study of evolution until it is thoroughly studied at KS4.'

'I was really pleased by what I read. I am sure that these activities would adequately prepare students for secondary school - there is a lot of overlap which would allow for cementing of knowledge.'

'The sequence of teaching these ideas is potentially important. At KS4 students are also asked to consider the notion that scientists are not always correct in their theories and that some who are later found to be correct may be ridiculed for their ideas.'

6. We would be grateful to have any other comments, suggestions, criticisms or observations that you feel may support the idea of 'secondary readiness' for KS2 pupils and helpful to continuity and progression in the transition from KS2 to KS3.

One criticism of the published account of the KS1-2 research and classroom activities expressed by one respondent was its piecemeal nature. This is at least in part a result of the sequential reporting by theme that followed the chronology of the research outcomes as they were revealed. It was suggested that a summary overview drawing out the interlinked nature of the various activities would be helpful.

'It would be helpful to have the tasks suggested mapped by idea and year…' here:

'*The articles could be written to flow; at the moment, the ideas seem fragmented. A sixth article linking them together and providing a big picture is desirable.* [If] *I'm a science leader in a primary school – where do I start?*'
However, we would stop short of meeting the request for a mapping of sub-themes or topics by year group as was suggested by one respondent. In looking at progression, we explored with teachers the qualitatively different approaches to the same ideas in age-appropriate ways. This led us to propose certain activities as possible for children at a younger age than is conventionally assumed to be viable. A case in point is the argumentation process which, with appropriate scaffolding in the form of choice of content area, teacher management and reference to real objects (rather than 'pure ideas') proved to be possible with children at KS1. The sort of branching progressions described in the AAAS publications (AAAS, 2001) we would consider to be more likely to convey the developmental subtlety that we have in mind. A grid of sub-topics by year group carries the danger of attracting mechanical teaching rather than a response informed by formative assessment.
'…my main concern would be the lack of continuity at KS3 as this topic is barely mentioned before being studied at depth at KS4…teaching of evolution at KS2 would be of value and certainly help with 'secondary readiness' and progression with regard to current KS4. It is at KS3, however, that I feel the continuity is broken and this would need addressing.

The idea of the necessity of progression in teaching and learning was met with sympathy, as was the enquiry approach:

'I've seen across this work an emphasis on student enquiry, I feel this is a real positive…. what students have studied appears to have more relevance to Key Stage 4, but I feel that is a shortcoming of the Key Stage 3 that I'm currently teaching, rather than this work. I am inspired to rewrite the 'Genetics and Evolution' Scheme of Work I currently teach.'

'I think the best approach is clear links forged between Primary and Secondary schools…. Reading the articles fills me with ideas and excitement of what happens in a classroom to develop young children's interest and understanding, but still being left with that realisation of other unavoidable factors influencing the level of teaching and the topics being explored.' The 'unavoidable factors' this respondent had in mind related to primary science teaching variability. He was not alone in this concern.

'Good subject knowledge by the primary teacher is also required in order to address and dispel possible misconceptions in the study of this topic.'

'Completing this project has me think a lot more about what pupils learn at KS2. Whilst I have looked through the KS2 curriculum, I never really thought about the sort of activities pupils complete to help them learn new material. It seems to me that the activities/experiences you have described will give pupils an excellent background in this area.'

'Overall in my experience the vast majority of year 7 pupils have huge enthusiasm for science and its often one of their favourite subjects. By increasing the 'secondary readiness' of all pupils, I think this would only help to increase enthusiasm by building confidence in pupils' ability and promoting their curiosity.'
Provision of information to secondary teachers concerning primary science experiences of students would be invaluable.'

Particularly heartening was the way that the KS3-4 teachers' love of their subject and enthusiasm for its promotion amongst younger children in readiness for the secondary school experiences that awaited them shone through.
'I have really enjoyed reading these materials. I like the idea of breaking down the topic into 'fundamental ideas' and tackling the complex subject matter with 'baby steps'. The teaching ideas that I have read about were actually quite inspiring and I am sure would adequately prepare students for the next step of their education. I have been surprised to read what students were capable of grasping at this level and I have found it reassuring given the increasing difficulty of the subject matter at each key stage.'

' I think the work you describe from KS2 is fantastic and students lucky enough to benefit from such experiences will come well prepared to KS3 and KS4 science.'

'I think that the deep research and metacognitive approach to children's understanding of these very abstract ideas is so valuable, and I commend the researchers. If the ideas are implemented successfully in the curriculum, I believe the secondary readiness will be markedly improved and feed us children that are intrinsically and extrinsically motivated to learn more about their place on earth, with a strong foundation already in place.'

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