Evolutionary tree design: An exploratory study of the influence of linear versus branching format on visitors' interpretation and understanding across age groups

By

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Evolutionary tree design: An exploratory study of the influence of linear versus branching format on visitors' interpretation and understanding across age groups

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ABSTRACT

This exploratory study sought to investigate the influence of tree graphic design—specifically linear versus branching depictions of taxa—on visitors in three different age groups (aged 11-13, 14-18, adults) interpretation and understanding using a multiple-case study strategy. The findings from this research indicate that linear and branched depictions elicit qualitatively different narratives and explanations about the relationships between the taxa in all age groups. Branched tree graphics support scientifically appropriate explanations of evolutionary relationships, i.e. that taxa are related via shared or common ancestry; while linear representations reinforce intuitive interpretations of ancestor-descendant or anagenic relationships. Furthermore, differences in the language used for linear and branched trees suggests that there is a spectrum within an analogy of developmental change that is thought to serve as a transitional concept between intuitive and scientific understanding—with 'evolved from' for branched depictions of taxa representing a shift towards an interpretation of shared ancestry rather than an individual transformation from one thing into another.

In addition, branched graphics appear to support the correct reading and interpretation of shared or common ancestry in tree diagrams. Mixed reasoning was common and overall reasoning patterns were broadly similar among participants in all age groups, however, older youth (aged 14 to 18) and adults often provided more detail in their explanations and sometimes included references to evolutionary ideas such as variation, inheritance and selection.

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CHAPTER I: INTRODUCTION

As buds give rise by growth to fresh buds, and these if vigorous, branch out and overtop on all sides many a feebler branch, so by generation I believe it has been with the great Tree of Life, which fills with its dead and broken branches the crust of the earth, and covers the surface with its ever branching and beautiful ramifications. Charles Darwin, On the Origin of Species (1859).

The concept of a 'tree of life' is widespread across diverse cultures, appearing in folklore, as a recurring theme in mythologies throughout the ancient world, and in religious and scientific texts (Cook, 1974). In ancient traditions, the tree of life is a central symbol that unites the spiritual and earthly processes—representing a range of concepts such as wisdom, protection, strength, and bounty. In the Kabbalistic Jewish tradition, the tree of life represents the ten interconnected spheres depicting a map of the universe and the path to spiritual illumination. Taoist teachings represent the tree of life as offering the gift of immortality. The idea of a tree of life is represented in nearly every ancient and modern religion, as well as being used as a symbol of ecological-spiritual explorations and harmony, and broader environmental messages.

Two hundred years ago, Jean Baptiste Lamarck first presented an evolutionary tree of animals (Figure **1**) (Lamarck, 1809; Wheelis, 2007). Sixty years later, Charles Darwin (1838) also sketched relationships of organisms in both space and time in a graphic representation of the tree of life (Figure **2**). Since then, the tree of life has served as an organizing principle in biology, "…a cornerstone in evolutionary theory that, as well as classifying organisms, has the potential to make sense of all biology" (Graves, 2003, p. 1621).

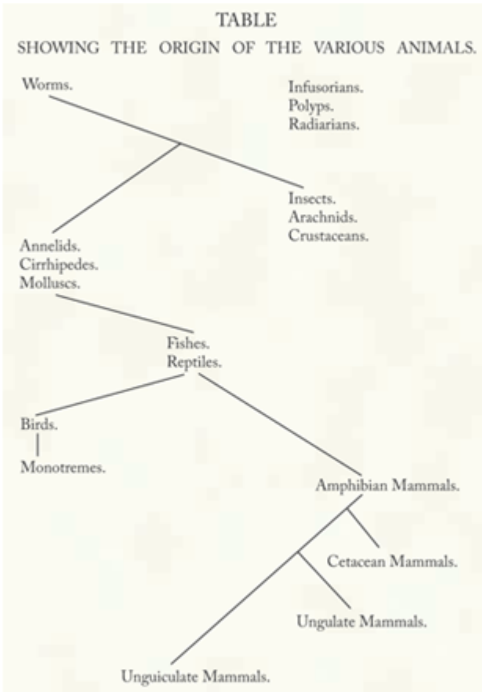

Figure 1 First tree of animals by Lamarck (Lamarck, 1809).

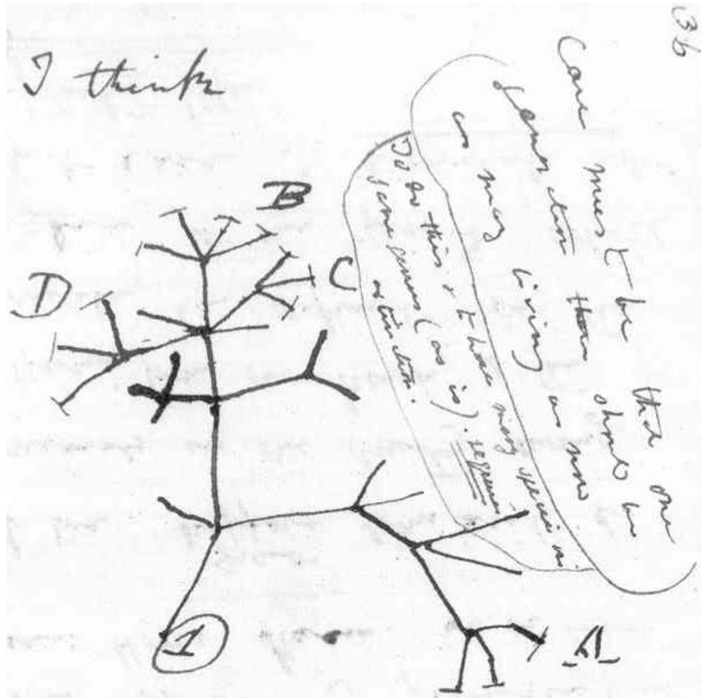

Figure 2 Tree diagram from Darwin's notebook B, 1838 (http://darwin-online.org.uk).

Today, the tree of life represents a core concept in the teaching of biology, namely phylogeny. Phylogeny charts the evolutionary history of life, and represents the relationships of lineages as they change through time. While the tree of life is included in many biology textbooks, it often is presented alongside the five kingdom system of organization that most people are familiar with; however, the five (or six) kingdom system is no longer appropriate for thinking about the diversity of life on Earth and the relationships between organisms as it does not convey the complexity and diversity of life, and in many cases does not reflect the phylogenetic principles (e.g. it includes paraphyletic groups) that are the basis for understanding and studying evolution (Woese, 1990).

The National Academy of Sciences content standards for biology (National Research Council, 1996) included two key concepts related to phylogeny:

- The millions of different species of plants, animals, and microorganisms that live on earth today are related by descent from common ancestors; and
- Biological classifications are based on how organisms are related. Organisms are classified into a hierarchy of groups and subgroups based on similarities that reflect their evolutionary relationships. (p.185).

The Atlas for Science Literacy (American Association for the Advancement of Science, 2001) maps out the tree of life in the following way:

> Evolution builds on what already exists, so the more variety there is, the more there can be in the future. But evolution does not necessitate long term progress in some set direction. Evolutionary change appears to be like the growth of a bush: Some branches survive from the beginning with little or no change, many die out altogether, and others branch repeatedly, sometimes giving rise to more complex organisms. (p.83)

In the 2013 Next Generation Science Standards (NGSS Lead States, 2013a), an understanding of relatedness, shared evolutionary history and the supporting evidence represents an important part of the disciplinary core ideas for *Biological Evolution: Unity and Diversity*, outlined in the *Evidence of Common Ancestry and Diversity* (LS4.A), for example:

- Some living organisms resemble organisms that once lived on Earth. Fossils provide evidence about the types of organisms and environments that existed long ago.
- The fossil record documents the existence, diversity, extinction, and change of many life forms and their environments through Earth's history. The fossil record and comparisons of anatomical similarities between organisms enables the inferences of lines of evolutionary descent. (p. 7)

In biology, the image of a tree largely has been replaced by more functional and accurate representations while still being referred to as trees of life, or evolutionary or phylogenetic trees. According to Lecointre & Le Guyader (2006), a phylogeny can be represented as a tree diagram, but a tree is not necessarily a phylogeny. Mathematically speaking, a tree or dendrogram is a non-cyclic connected graph that can be used to symbolize a hierarchy. A tree becomes phylogenetic in the context of the evolutionary hypothesis being made by the biologist when applying the classification method.

Even as a metaphor, some biologists argue that a tree is not the best image for conveying evolutionary relationships, and that the occurrence of hybridization events and other processes across a wide range of taxa requires the use of a very different topology (Doolittle, 2000; Embley & Martin, 2006; Gogarten, 2000; Lawton, 2009; W. Martin & Embley, 2004). According to Brooks and Hoberg (2008), a tree concept may not capture the complexity of evolution:

> By referring to species as “communities of descent”, and placing them in a single “Tree of Life,” Darwin emphasized that the fundamental explanatory principle in evolution is shared history among organisms and species.

They cite Darwin’s recognition of this complexity by his use of an additional metaphor, ‘a tangled bank’ representing ecological associations:

> It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from one another, and dependent upon each other in so complex a manner, have all been produced by laws acting around us. (Darwin, 1947, p. 429)

Grant and Grant (2002) also question the utility of a tree image. The metaphor of an evolutionary tree, they point out, deflects us from seeing species hybridization and that the ancestors of modern species may have become extinct without their derived branches doing so. They suggest an alternative that avoids these two unrealistic features of trees might be a river that divides several times as it runs across a landscape: “This is closer to the metaphor of an adaptive landscape… and has the interesting implication that speciation—the evolution of isolated gene pools—requires special, rare and perhaps capricious circumstances, like floods”

(p. 139). Most trees, however, do not reflect this complexity of evolution (Brooks & Hoberg, 2008), and museum trees generally focus on vertebrates, for which the general consensus is that hybridization plays only a minor role (Dowling & Secor, 1997). Moreover, Mindell (2013) argues that the tree of life as metaphor and model remains a valid and useful organizing principle for evolutionary history and heuristic for evolutionary research.

Despite these discussions about the limitations of a tree metaphor, the concept of a tree of life continues to be used and reflects the standard in the scientific and education communities, and therefore is reflected in media coverage of that research (Grant & Grant, 2002; Spinney, 2007; Stevens, 1999; Wade, 1998; Zimmer, 2008). It also is a common theme in popular science books for both children (Jackson, 2004; Sis, 2003; Strauss, 2004; Westberg Peters, 2003) and adults (Dawkins, 2004; Eldridge, 2005; Shubin, 2008).

To biologists, the tree of life represents a hypothesis, a dynamic model that depicts proposed evolutionary relationships (Lecointre & Le Guyader, 2006). Our understanding of the tree of life has changed dramatically in response to novel ideas and new analytical tools. Research during the last few decades, including the use of molecular techniques, digital archives and computer processing has resulted in fundamental shifts in our understanding not only of the history of life on Earth, but also of how all of life is organized. An international endeavor is under way to resolve phylogenetic relationships and to reconstruct the evolutionary history of all known organisms (Assembling the Tree of Life, http://tolweb.org/tree/). The importance of phylogenies and what they represent has not been communicated adequately to the general public, and our understanding of how they are interpreted is limited.

Students see different depictions of the tree of life—in some cases inaccurate and misleading ones—in their textbooks across the years when they are in school, and these often are presented alongside introductions to widely varying biological classification systems (Catley & Novick, 2008). In natural history museums and other informal science education settings, visitors also can see a wide range of depictions of the tree of life (MacDonald & Wiley, 2012). Each new exhibit updates the graphic representation of the tree in accordance with current usage or discipline preferences, but the older depictions often are kept on display, so one can view a range of different presentations of tree diagrams even within a single institution (Diamond & Scotchmoor, 2006). Some galleries, for example the NSF-funded *Explore Evolution* exhibition, intentionally use more than one depiction of the tree of life to emphasize to visitors the validity of alternate approaches or to highlight different elements (Diamond, 2005). Scientific articles are doing this as well (Kaessmann & Pääbo, 2002).

Educators and scientists recognize that approaches and resources to present phylogenies in a meaningful way to facilitate thinking strategies for understanding the tree of life—“tree-thinking skills”—are critical to improving the understanding of evolution (Baum, DeWitt-Smith, & Donovan, 2005; Baum & Offner, 2008; Catley & Novick, 2006; Donoghue, 2005; Donovan, 2005; Novick, Schreiber, & Catley, 2014). Phylogenetic trees are a graphic representation of evolutionary history, and so illustrate the principles of common ancestry, relatedness and shared history. How evolutionary trees are presented to and used by visitors may influence their effectiveness in reinforcing fundamental concepts about evolution (Diamond & Scotchmoor, 2006).

One of the challenges to understanding the tree of life is supporting the development of these tree-thinking skills—as a way of conceptualizing biological phenomena through a phylogenetic perspective (Baum, et al., 2005). In terms of tree of life diagrams, this requires not only interpretation of the graphic representation of the tree itself, but also a grasp of underlying concepts such as relatedness, ancestry and time.

Rationale for Study

Phylogeny is of increasing importance in biological research with implications for studying disease, making informed decisions about conservation, identifying important biological compounds, and much more (Cracraft & Donoghue, 2004). A grasp of this fundamental concept is important to developing an understanding of the concepts and processes of biological evolution.

Common misconceptions in tree reading and interpretation are well documented and relate to issues of the diagrams themselves as well as the interpretation and meaning of the patterns represented in them (Gregory, 2008). Studies of biology textbooks suggest that many tree diagrams are confusing and may reinforce misconceptions about evolution (Catley & Novick, 2008), and the absence of a phylogenetic framework in K-12 education has been identified as a "glaring omission" in evolution teaching (Catley, Lehrer, & Reiser, 2005). If we consider a broader educational framework, trees form a major graphic element in informal science learning settings, are highly variable, and share many problematic elements (Diamond & Scotchmoor, 2006; MacDonald & Wiley, 2012; Novick, et al., in press; Torrens & Barahona, 2012).

Research on the visual representation of evolutionary relationships, specifically the role of graphic elements used in tree diagrams, has focused primarily on cladograms (one tree type) in higher education settings, and has found that certain design elements can impact students' ability to read and interpret trees. Limited research, however, has been done to date exploring the potential role of tree design outside of a formal instructional framework or with younger learners. Given the critical role that museums and other informal education environments play in presenting and teaching about evolution (Diamond & Evans, 2007; National Science Board, 2008), increasing our knowledge and understanding of how visitors think about trees, and the influence of graphic elements on their understanding, can help to improve tree design and hence their effectiveness at communicating about phylogeny and tree of life. Moreover, since families and school groups represent a significant museum audience, informal environments provide an important opportunity to introduce evolutionary ideas to young learners.

The qualitative study presented herein seeks to improve our understanding of how different representations and particular graphic elements used in tree diagrams influence how they are interpreted and understood in an informal learning setting and within a developmental perspective. I use a multiple-case study approach to investigate the impact of linear versus branching depictions of taxa on participants' understanding of trees and the relationships depicted across different three age groups (11-13 years, 14-18 years, and adults).

Research Questions

Specifically, the following questions are explored:

(1) How does taxa placement as a result of linear or branched depiction influence narratives about phylogenetic trees?

(2) How does taxa placement as a result of linear or branched depiction affect the reading and interpretation of trees?

(3) Do the relationships between tree design, narratives and interpretation vary by age?

CHAPTER II: LITERATURE REVIEW

Phylogenies and Evolutionary Tree Diagrams

Dendrograms are branching diagrams that can be used to depict any kind of hierarchical relationship with the tips (leaves) of the graph connected to the nodes (vertices) by branches (edges). Phylogenies are essentially a form of dendrogram that depict a historical pattern of divergence and descent as a series of branches. These branches merge at points representing common ancestry, which in turn are connected with more distant ancestors. The key parts of a tree diagram are the nodes, branches and the root. The terminal nodes or tips of the tree represent the taxa (organism or group of organisms) whose relationships are being shown; the nodes represent ancestral species; these are connected with other taxa through branches that join at internal nodes—these represent a relationship term; and the outgroup is the most distantly related taxon in the tree, used to root the tree and indicate the most recent common ancestor shared by all the taxa (Figure **3**).

Alternatively, the internal nodes can represent speciation events with segments of the 'main branch' from the root representing ancestral species, and branches to the tips depicting lineages evolving through time (Wiley, 2008, personal communication). The two forms are equivalent and can be converted to have ancestral species as edges (branches) or nodes (vertices) (Martin & Wiley, 2008). It is important to note that evolutionary trees are not fixed, but rather represent hypotheses about evolutionary relationship that can be used to study patterns of evolution; this is another area of difficulty when it comes to understanding phylogenies (Catley, 2006; Donovan & Hornack, 2004).

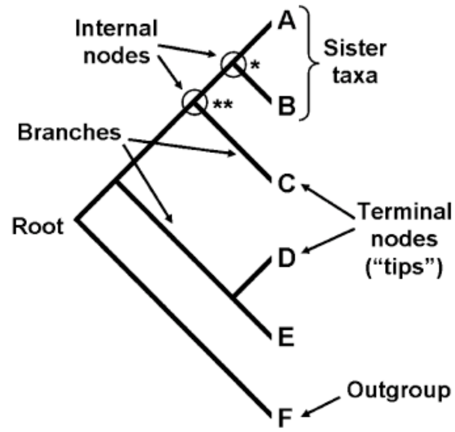

Figure 3 Anatomy of a phylogeny (Gregory, 2008).
*most recent common ancestor of A & B; ** most recent ancestor shared by A, B & C

There are three broad categories or forms of tree diagrams used in biology (Lecointre & Le Guyader, 2006): (1) cladograms—phylogenies that show branching order and depict the inferred phylogenetic relationships among the taxa based on synapomorphies or shared derived characteristics (Figure **4**); (2) phylograms—cladograms in which branch lengths are proportional to the amount of evolutionary time inferred between nodes (Figure **5**); and (3) phenograms—representations of the overall similarity between taxa based on phenetic (observable) characteristics, including molecular distances, in which branch lengths are proportional to some measure of similarity or divergence between species. These distances may or may not reflect evolutionary relatedness (i.e. be based on synapomorphies).

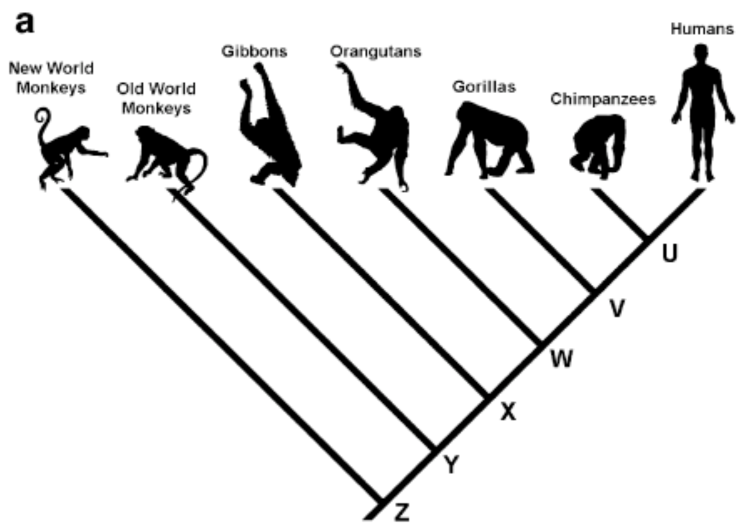

Figure 4 Cladogram with select primates (Gregory, 2008).

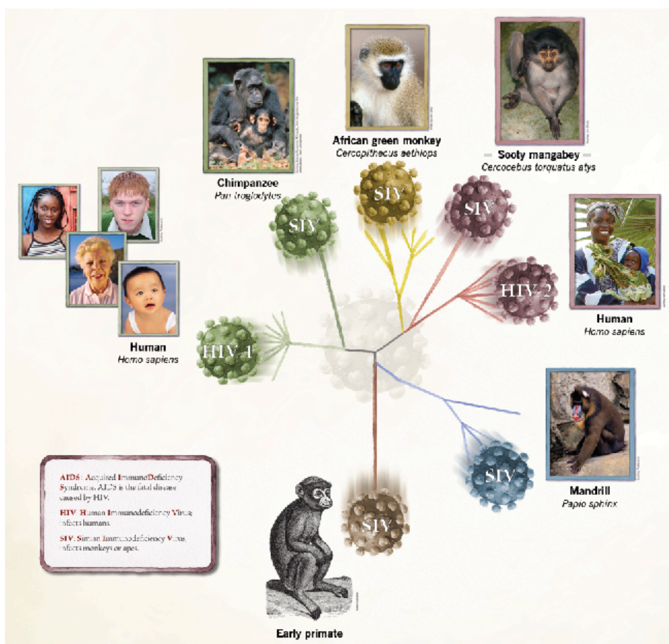

Figure 5 Phylogram of HIV and SIV (from the *Explore Evolution* exhibit, UNSM Angie Fox and SMM Illustration, 2005).

There also are graphics that might be thought of as cladograms, or perhaps phylograms, in the broadest sense as their branching pattern depicts evolutionary relatedness, but they violate one or more cladistic principle such as including anagenesis. These diagrams often are designed to provide information in addition to branching order such as geographical distribution or diversity (Figure **6**). The representation of the information in these diagrams varies considerably in terms of overall layout, line characteristics and orientation, and other elements. “Evolutionary tree” then broadly refers to a graphic that depicts evolutionary relationships, whereas cladogram refers to a specific tree type. For a description and discussion of tree types in textbooks see Catley and Novick (2008), for museums see MacDonald and Wiley (2012); a detailed analysis of the divergent and shared ideas among tree types and their authors can be found in Fisler and Lecointre’s (2013) “*A Tree of Trees”*.

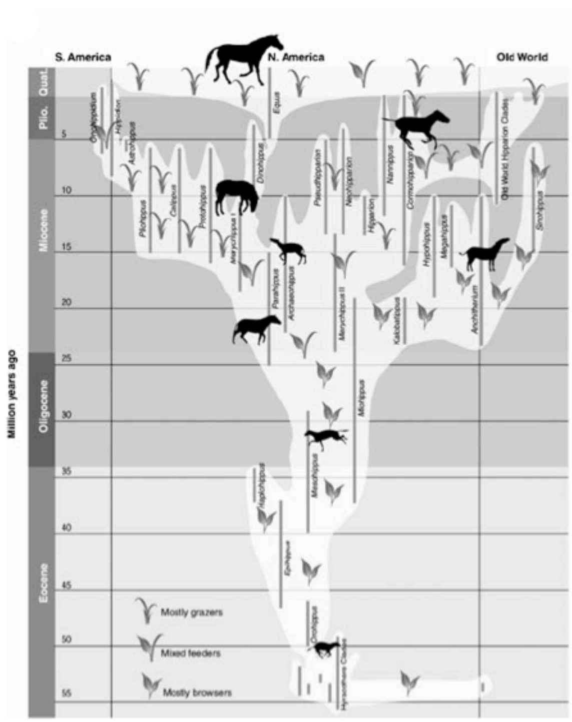

Figure 6 Tree that includes geographical distribution and feeding ecology of horses (McFadden, 2005).

Understanding Phylogeny

Phylogeny is the history of organismal lineages as they change through time and, as such, forms the foundation of biology. Evolutionary or phylogenetic trees are a graphic representation of evolutionary history—a diagrammatic depiction of taxa that are connected through common descent. An understanding of evolutionary trees, diversity, and similarities that can be used to infer relatedness and shared history forms the basis for developing an understanding of the unifying concepts and processes of biological evolution (American Association for the Advancement of Science, 1993; Baum, et al., 2005; National Academy of Sciences, 1998; National Research Council, 1996).

Despite its importance, phylogeny is often poorly understood; the diagrams that are used to represent evolutionary relationships are problematic for novices and professionals alike. Key issues related to understanding phylogenies fall into several broad categories:

- Interpretation of graphics—representations convey meaning, but can create/reinforce misunderstandings about evolutionary relationships depending on the orientation and type of diagram, location of taxa, line length, time axis, etc. (Baum, et al., 2005; Catley & Novick, 2006; Donoghue, 2005; Donovan, 2005; Gattis, 2004; Giusti & Scott, 2006);
- Confusion about evolutionary concepts—the association between concepts of relatedness, similarity and common ancestry (Barrett, 2004; Boster & Johnson, 1989; Springer, 1995, 1996; Springer & Keil, 1989);
- Trees as hypotheses rather than fixed constructs—difficulty with the idea that phylogenies are hypotheses of evolutionary relationships (Catley, 2006; Donovan & Hornack, 2004);
- Classification and phylogeny—teaching classification independent of phylogeny can create difficulties in grasping broader evolutionary concepts later (Brumby, 1984; Griffiths & Grant, 1985; O'Hara, 1992; Trowbridge & Mintzes, 1988; Yen, Yao, & Chiu, 2004);
- Novice versus expert conceptual understanding of representations and reasoning applied to tree diagrams (K. C. Anderson & Leinhardt, 2002; Evans, Rosengren, Lane, & Price, 2012; Hackling & Garnett, 1992; Halverson, Abell, Friedrichsen, & Pires, 2009; Heyworth, 1999).

Teaching and Learning about Phylogeny

Learning about the relationships between, and classification of, animals occurs at nearly all ages from preschool on, but little is known about how children construct their notions about phylogenetic relationships. Our current understanding of evolutionary relationships, and approaches to reconstructing phylogenies, are not reflected in how this subject is taught. Some research suggests that learning higher order concepts such as ecology and evolution may be impacted negatively by conceptions relating to less inclusive ideas, such as classification (Brumby, 1984; Griffiths & Grant, 1985; Novak & Gowin, 1984). Donovan & Wilcox (2004) suggest that explicitly linking classification with phylogeny can aid in the recognition of evolutionary patterns, which in turn connects to the very purpose of phylogenetic systematics.

During the elementary school years, students begin to explore the nature of living organisms and evolutionary ideas such as the characteristics of different groups, variation, heritability, differential reproduction and adaptation. Middle school-aged youth should gain an understanding of the diversity of organisms and the similarities that can be used to infer their relatedness and shared history. The core evolutionary ideas of variation, inheritance, adaptation, natural selection, common ancestry and diversity are then further developed and integrated in high school (American Association for the Advancement of Science, 1993; Catley, Phillips, & Novick, 2013; National Academy of Sciences, 1998; National Research Council, 1996).

A review of K-12 evolution teaching (Catley, et al., 2005) suggested that the complexity of evolutionary processes can result in difficulties in understanding evolution as an explanation for the diversity of life on Earth. This indicates that careful attention needs to be paid to the treatment of central evolutionary concepts throughout the entire school system. The omission of a phylogenetic perspective in schools—the concept of monophyletic groups as an organizational framework—is thought to be particularly problematic, and is an issue internationally (American Association for the Advancement of Science, 2001; Catley, 2006; Catley, et al., 2013). Catley et al. (op cit.) suggest that "without a phylogenetic perspective an understanding of the full gamut of evolutionary process cannot be developed." (p. 17).

Classification and phylogeny are related but distinct concepts that serve different purposes. Classification—the naming and grouping of organisms—is extremely valuable for trying to grasp the incredible diversity of life, and provide a means of talking about it; but it does not necessarily reflect the evolutionary history or phylogeny that created that diversity. While there should be correspondence between the two—i.e. a name used in classification should ideally refer to a single branch of the evolutionary tree (monophyletic group)—nomenclature is a tool, not the purpose for studying diversity.

Scientists in the Assembling the Tree of Life (http://tolweb.org/tree/) project argue that introducing students to diversity through names rather than the ideas that form the foundation of the scientific study of diversity is confusing and misses the point. Indeed, conceptual difficulties with biodiversity seem to undermine the acquisition of broader biological ideas (Adeniyi, 1985). Yen et al. (2004) found that misconceptions about amphibian and reptile classification, such as the notion that turtles are amphibians because they live in water, develop before and during the early school years, and persist into adulthood.

Classification may be a good starting point for talking about diversity due to its familiarity and because it reflects some of the intuitive ways young people think about living things such as essentialism, the sense there is a set of properties that all entities of that kind possess, and teleology or design-based reasoning (Atran, 1995, 1998; Evans, 1991, 2000, 2006, 2008; Medin & Atran, 2004). Studies of folk biological taxonomy has found that humans naturally and spontaneously create conceptual hierarchies that organize knowledge and guide inferences about biological categories based on similarities in morphology, behavior and ecology. These categories, however, do not align with scientific groupings based on phylogeny and therefore might make thinking about grouping by evolutionary lineages challenging (Coley & Muratore, 2012). In addition, studies on the development of the different levels of biological categorization (basic, subordinate and superordinate—e.g. dog, poodle and mammal, respectively) indicate that there is a complex relationship between the perceived similarities of objects, learned taxonomic groupings, biological knowledge, and language in how people identify and understand biological categories.

The chronology and relationship between perceptual and conceptual categories is complicated—subordinate categories are considered concrete and based on readily perceived features, basic levels are intermediate in terms of abstractness, and superordinate share even fewer perceptual features. For example, work with non-human primates suggests that other apes (as well as some monkeys) can engage in forming basic and more abstract levels of biological categories without specific instruction (Murai, Tomonaga, Kamegai, Terazawa, & Yamaguchi, 2004; Vonk, 2013; Vonk & MacDonald, 2002, 2004).

Overall, biological categorization does not appear to be based exclusively on the perceptual features of organisms, which often become less informative for identifying features that relate to more abstract category levels—e.g. characters that are indicative of phylogeny rather than shared superficial similarity (Coley, 2007; Gelman & Davidson, 2013).

Furthermore, young children do use ideas about descent when thinking about living things (e.g. their own family) and so classification could be used as a transitional step to introducing more evolutionary related ideas (Springer, 1992, 1995, 1996; Springer & Keil, 1989). Moreover, research suggests that the development and persistence of alternative/misconceptions about animal classification results from the teaching of classification independent of phylogeny (Brumby, 1984; Griffiths & Grant, 1985; O'Hara, 1992; Trowbridge & Mintzes, 1988; Wellman & Gelman, 1998; Wiley, Siegel-Causey, Brooks, & Fund, 1991; Yen, et al., 2004). In terms of interpreting trees, studies have found that students use disconnected and inappropriate prior biological knowledge, such as shared ecology or categorical responses, when reasoning with trees (Catley, Novick, & Funk, 2012; Halverson, Pires, & Abell, 2011; Naegle, 2009; Phillips, Novick, & Catley, 2010).

This prior work suggests that introducing the idea of the tree of life early on in learning—when ideas about classification, variation, similarity and inheritance are being explored—may help to establish phylogeny as an underlying, unifying principle of biological information that is central to how biologists investigate questions rather than as an isolated topic (Green & Shapely, 2005). An understanding of how the graphics used to communicate about the tree of life are interpreted in learners of different ages is an important part of supporting effective teaching about these ideas.

Misconceptions (Intuitive Interpretations) of Evolutionary Trees

Misconceptions or intuitive interpretations in reading phylogenies relate to both the reading of the diagram itself, and to the interpretation and meaning of the patterns represented in them. Table 1 summarizes the misconceptions presented in Gregory (2008), which in turn summarizes the research of others (see below).

Table 1 Misconceptions in interpreting tree diagrams and related evolutionary concepts.

<u>Higher and lower</u> – there is a "Great Chain of Being" or *scala naturae*; taxa can be ranked from 'lower' to 'higher' with humans at the top (Nee, 2005; O'Hara, 1992, 1997).
<u>Main line and side tracks</u> – some branches are seen as side tracks and others as progressive along a main line (Crisp & Cook, 2005).

<u>Tip reading/proximity=relatedness</u> – reading the order of the terminal nodes across the top, rather than the branching pattern, as relatedness (Baum, et al., 2005; Catley & Novick, 2006; Catley, et al., 2012; Halverson, et al., 2011; Meir, Perry, Herron, & Kingsolver, 2007).
<u>Similarity versus relatedness</u> – that overall similarity indicates relatedness; the branching pattern (e.g. dinosaurs closer to birds than crocodiles) may be inconsistent with intuitive sense of similarity. Confusion about the association between concepts of relatedness, similarity and common ancestry (Barrett, 2004; Springer, 1995, 1996; Springer & Keil, 1989).
<u>Sibling versus ancestor</u> – that closest living relative (sister taxa) means that one modern group is the ancestor of the other (Barrett, 2004; Catley, et al., 2012; Springer, 1995, 1996; Springer & Keil, 1989).
<u>Long branch implies no change</u> – a long line represents a lineage in which no change has occurred (Crisp & Cook, 2005; Novick & Catley, 2007).
<u>Different ages for modern species</u> – a group identified as being older (appeared as a recognized taxa before other e.g. fish before mammals) is less evolved, and a more recent group as having a younger lineage age (Crisp & Cook, 2005).
<u>Misreading time</u> – reading time across the tips, rather than root to tips (Catley, et al., 2012; Meir, et al., 2007). This often leads to confusing siblings and ancestors, and difficulty in reading the tree graphic (Giusti & Scott, 2006).
<u>Node counting</u> – more nodes means they are related more distantly (Catley, et al., 2012; Meir, et al., 2007).
<u>Change at nodes only</u> – view nodes as the precise moment of change in a particular organism, when it is not necessarily the case and it might represent a diverse assemblage of organisms (Catley, et al., 2012; Halverson, et al., 2011; Meir, et al., 2007).

Several of these intuitive interpretations have potential links to the role of linear versus branching taxa depiction in tree graphics. For example, a sequential representation of taxa along a single branch, particularly vertically, is likely to be more consistent with the idea of a 'lower to higher' ranking of taxa. This idea of the *scala naturae* or 'great chain of being' (Bonnet, 1745; Lovejoy, 1936) represents an inaccurate, teleological view of evolution; there is no general pattern of directed progress in evolution. In addition, interpreting the relationships between taxa as siblings or ancestor-descendant, and the pattern of evolutionary change are areas of interest.

A 2008 study (Catley & Novick) analyzed the evolutionary tree diagrams found in 31 biology textbooks ranging from middle school to undergraduate level. One issue the authors cite is the depiction of anagenesis, one taxon turning into another, as opposed to cladogenesis or branching events (see Figure 7). They argue that overall, current evolutionary thinking views speciation events as where one species split into two with the new taxa sharing a most recent common ancestor. Of particular concern to Catley & Novick (op cit.) is the prevalence of this type of depiction in diagrams that include humans.

Figure 7 Topology of noncladogram evolutionary diagrams, anagenesis (Catley & Novick 2008).

MacDonald and Wiley's (2012) review of museum trees found that many of the same potential barriers to understanding trees are present in museum graphics, including anagenesis or the linear depiction of taxa along a branch (see Figures 8 to 10 as examples); though less frequently than textbooks with regards to trees that include humans. An important difference to note between textbook and museum trees is that exhibit graphics are typically associated with specimens or other exhibit components.

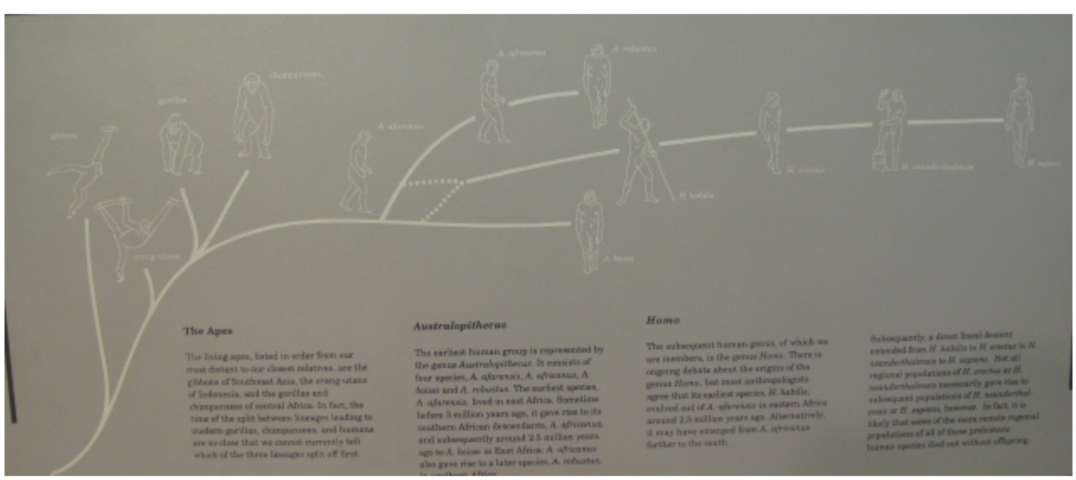

Figure 8 Maxwell Museum of Anthropology, hominids (humans and recent extinct relatives), 1990. Courtesy of the Maxwell Museum of Anthropology.

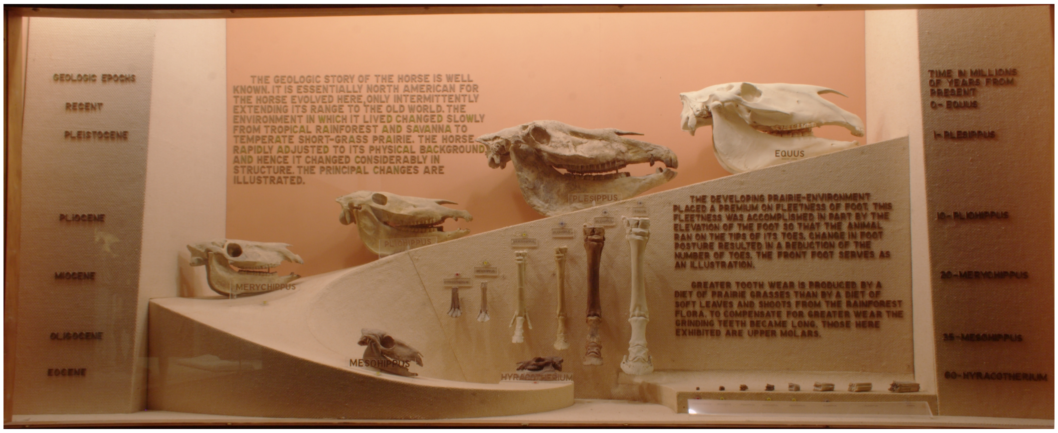

Figure 9 University of Kansas Natural History Museum, horses, 1955. Courtesy of the University of Kansas Natural History Museum. (Note: exhibit was redesigned in 2014).

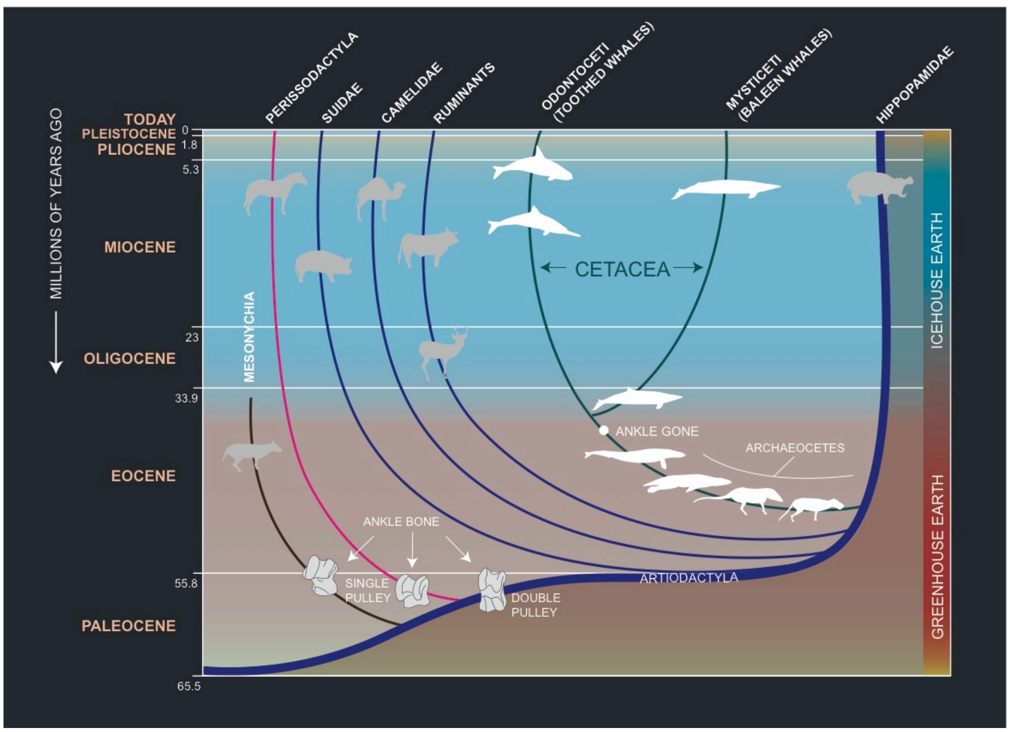

Figure 10 Smithsonian National Museum of Natural History, whales and close relatives, 2008. Courtesy of Mary Parrish/Smithsonian Institution/National Museum of Natural History/Sant Ocean Hall.

Cognitive Design Principles

Two key cognitive principles for designing effective visualizations are congruence and apprehension (Dwyer, 1978; Tufte, 1983; Tversky, Morrison, & Betrancourt, 2002). The principle of *congruence* states that the structure and content of the visualization should correspond to the desired mental structure and content; and the principle of *apprehension* indicates that the structure and content of the visualization should be perceived and comprehended readily and accurately. In other words, diagrammatic space should be used to reflect conceptual space—which need not be an accurate representation of the spatial relationships, but rather reflect the schematic view of that information (Tversky, 1981). For example, mapping quantitative increases from bottom to top, or upwards, would illustrate both congruence and apprehension as it reflects underlying mental spatial relationships and supports the perception of that relationship.

Essentially, representing information in a simplified, schematic way that reflects cognitive structures facilitates apprehension as well as congruence. Overall, schematic visualizations need to convey the relevant, as well as remove irrelevant information that might interfere with extracting the pertinent information from the diagram (Tversky, 1981, 2000). From the perspective of evolutionary graphics and this study, an understanding of the impact of linear versus branching taxa depiction on reading and interpreting the graphic, as well as associated evolutionary narratives elicited, would be informative for thinking about these principles in tree design.

Visual Representation in Trees

How people interpret and understand evolutionary trees is a complex interaction between their prior knowledge and understanding (including intuitive conceptions) of underlying evolutionary concepts, as well as their ability to read the relationships depicted in a tree diagram. Studies have found that both novices and experts struggle with reading and interpreting trees (Baum, et al., 2005; Catley, 2006; Catley & Novick, 2006; Donoghue, 2005; Donovan, 2005).

Tree reading and interpretation reflect developmental and cognitive elements that are influenced by visual representation. Tree diagrams depict abstract structure and so their interpretation requires the transformation of graphic elements into a representation of abstract concepts (DuFour-Janvier, Bednarz, & Belanger, 1987; Hegarty, Carpenter, & Just, 1991; Novick, 2006(b)). Young children struggle with the concept of representation until middle childhood or aged 9-11 (Deloache, 2004; diSessa, 2004), and relating representations is difficult (Ainsworth, Bibby, & Wood, 2002). Children as young as seven, however, can reason with hierarchical dendrograms or tree diagrams, though their performance is influenced by number of levels of branching (Ainsworth & Saffer, 2013; Deneault & Ricard, 2005; Greene, 1989).

As visual representations, cladograms convey conceptual information, yet narrative interpretations of their space among novices reflect common evolutionary misconceptions. Matuk & Uttal (2012) proposed a framework for how folk biology and naïve evolutionary ideas are reflected in the narrative structures that influence cladogram reading and commonly identified misinterpretations—e.g. linear anagenic view of evolution, a directed progression from lower to more sophisticated forms (Figure **11**). In other words, issues with cladogram interpretation might be the result of an overarching narrative or storyline superimposed on the diagram. For example, each branching point is viewed as a point or step on the way towards a goal on the top right.

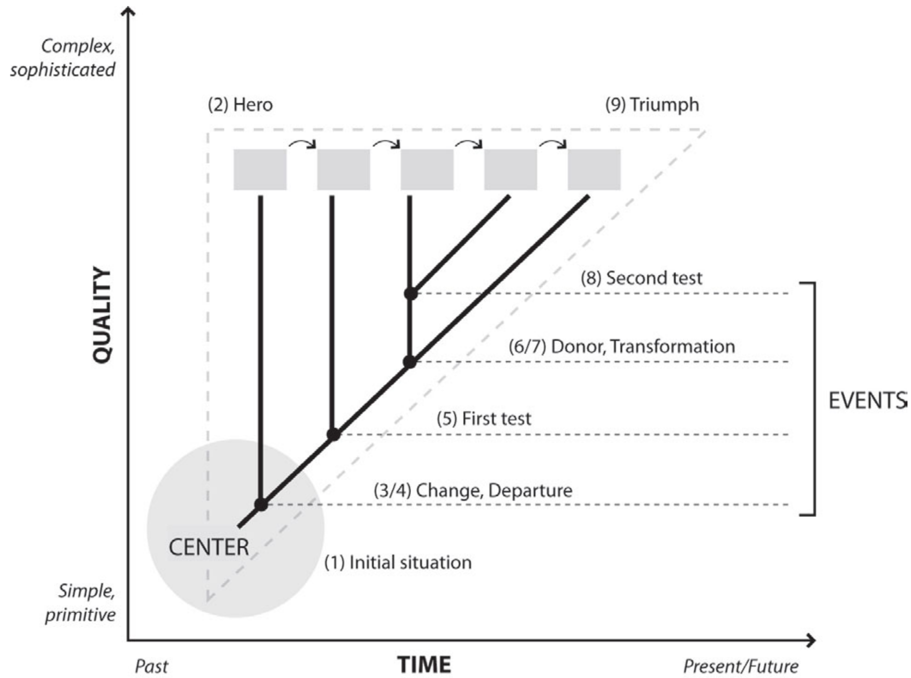

Figure 11 Map of cladogram narrative space illustrating how graphic elements might act as grammatical structures, e.g. taxa as characters acting towards a goal through a series of events from a beginning towards a determined end (Matuk & Uttal 2012).

Cultural narratives about evolution—whether scientifically accurate or not—are powerful and persistent (Hayles, 2001; Landau, 1984; Rudolph & Stewart, 1998; van Dijk & Kattmann, 2009), and many have become ubiquitous and entrenched (Scott, 2007). Visual reasoning requires the use of spatial elements to highlight conceptual relations and to represent meaning (Bauer & Johnson-Laird, 1993; Gattis, 2004; Gattis & Holyoak, 1996; Glenberg & Langston, 1992; Larkin & Simon, 1987; Tversky, 2001). Yet while spatial metaphors can be flexible, Gestalt processes—or how humans tend to interpret a visual field using cues such as similarity, proximity and continuity—and folk evolutionary narratives are not (Matuk, 2008, 2010). As noted earlier, the study presented here should provide an additional perspective to understanding the role of spatial relationships, evolutionary narratives and tree interpretation.

Natural History Museums and Evolution

Museums are an important part of how the public accesses scientific information, including evolution, and they play an important role in teaching about these ideas to their visitors (Diamond & Evans, 2007; McFadden, 2008; National Science Board, 2008; Suarez & Tsutsui, 2004; West, 2005). In fact, a recent study found that even a single visit to an evolution exhibit can influence children's thinking about evolutionary concepts (Diamond, Evans, & Spiegel, 2012). Museum visitors' interest in evolution is high, but their understanding of it is not. Prior knowledge and previous museum experience combined with intuitive reasoning, cognitive biases and other factors impact their interpretation and understanding of evolution exhibits (Spiegel, Evans, Gram, & Diamond, 2006). With one in every five adults in the United States reporting having visited a natural history museum or science center in the previous year, typically with family members including young children (National Science Board, 2006), informal institutions can play a critical role in communicating about evolution in social learning settings.

Research has shown that evolutionary explanations pose conceptual problems, and indeed are counterintuitive, as reflected by a set of cognitive biases highlighted by everyday explanations of the natural world (Evans, 2005, 2008; Evans, et al., 2006). These cognitive biases include: (1) essentialism – the idea that the world is unchanging, and things have some form of inherent quality that makes them a member of that group (e.g. dogs have a quality of 'dog-ness'), emerges in childhood and often persist into adulthood; (2) living organisms operate teleologically—with purpose or design. Intent within the context of evolutionary change include an extrinsic goal of a supernatural designer, intrinsic ones in which animals make a conscious decision or 'want' to change, and the purposeful 'need' to evolve a particular adaptation (Gelman, 2003; Medin & Atran, 2004; Wellman & Gelman, 1998). These biases, along with resistance to critical thinking and new ideas, result in a poor understanding of evolution (Sinatra, Southerland, McConaughy, & Demaste, 2003). Particular challenges exist when it comes to considering human beings within an evolutionary context; and these appear to be reinforced in many evolutionary diagrams (Catley & Novick, 2008; Tversky, 1995) and are found in popular books.

Evans et al. (2010) studied visitor explanations of evolutionary problems in a museum setting and found three categories of reasoning: (1) novice naturalistic – exhibit one or more of the cognitive biases mentioned above; (2) informed naturalistic – infer one or more evolutionary principles such as variation, selection, inheritance or time; and (3) creationist – invoke a supernatural explanation. Three key findings from the study reflect the complexity of communicating about and the understanding of evolutionary ideas: (1) all visitors exhibited mixed reasoning patterns with novice naturalistic reasoning being the dominant pattern (54%), followed by informed naturalistic (34%) and creationist (6%); (2) different organisms elicited different types of responses, with the question related to humans showing the most frequent use of creationist reasoning; and (3) visitor experience with museums impacted their form of reasoning, with more frequent visitation being correlated with an increased use of evolutionary ideas and terms.

The first finding is of particular interest since natural history museum patrons generally are well educated (Korn, 1995), are more likely to have been introduced to evolutionary principles in school, and generally are more accepting of evolutionary principles (Storksdieck & Stein, 2006). Evans et al.'s (2010) study in the United States suggests, however, that people tend to revert to intuitive reasoning patterns outside of a formal learning environment. In addition, a poor understanding of natural selection has been found in other English-speaking countries

(Silver & Kisiel, 2006) suggesting that misconceptions about evolution generally are consistent regardless of the level of acceptance of creationist views held in different countries (Miller, Scott, & Okamoto, 2006). The latter two conclusions from the Evans et al. (op cit.) study reiterate the importance of museums in communicating about evolution to the public, because most adults visit a natural history museum at some point in their lives (National Science Board, 2006). It also has potential implications for the presentation and portrayal of evolution in these museums.

Evaluation studies with natural history museum visitors show that they are interested in the tree of life, but struggle with interpreting the content and relationships represented in trees (Giusti & Scott, 2006; Spiegel, et al., 2006). While few museums use phylogeny as an organizing principle in their galleries, evolutionary diagrams form a major graphic element in many museums and other informal science settings (Diamond & Kociolek, 2012; Diamond & Scotchmoor, 2006; MacDonald & Wiley, 2012). In fact, Schueler & Karstad (2002) argued that phylogeny should be one of three key principles that should serve as a foundation for museum exhibits on evolution; tree diagrams would likely form an important part of this framework.

Museums have a long history of using evolutionary graphics to communicate about relationships (MacDonald & Wiley, 2012; Matuk, 2007; Torrens & Barahona, 2012), and while more common in natural history museums, diagrams about evolutionary history or relatedness are found in all types of informal science institutions (MacDonald & Wiley, 2012).

Learning Progression for Evolution

Learning progressions outline important ideas and how they are interconnected in relation to a particular topic providing a basis for advancing domain knowledge (Duschl, Schweingruber,

& Shouse, 2007). In essence, they are sets of successively more sophisticated ideas about a particular topic (Smith, Wiser, Anderson, & Krajcik, 2006).

In their proposed learning progression for evolution, Catley et al. (2005) noted the absence of a phylogenetic context in K-12 biology education and advocated for introducing the idea earlier in schools. Their framework regarding evolutionary trees recommends first making simple comparisons of similarities and differences between organisms using Venn diagrams, and then transitioning to using cladograms to depict organismal relationships in the upper elementary years and using these trees to make comparisons. Using cladograms as analytical tools to reason about characters and exploring homologous versus analogous structures would be investigated in middle school. This fits with Songer et al.'s (2009) classification link in their biodiversity learning progression in which the idea that organisms are grouped based on common structures, and that the patterns of shared characters reveals the evolutionary history of groups, would be taught in fifth grade. The introduction of tree reading early on is supported by a study of 7-11 year olds that found that children can reason using cladograms after only 15 minutes of instruction (Ainsworth & Saffer, 2013), and work with undergraduates indicated that tree reading skills develop before tree building ones (Halverson, et al., 2011). In addition, Novick et al (2014) demonstrated that an understanding of natural selection in college students was insufficient to develop tree-thinking skills; tree thinking must be separately and specifically taught.

Evans et al. (2012) proposed a general developmental learning progression for evolution in which natural selection and common descent are core, but separate, ideas that have different cognitive constraints and progressions. Also, that these are difficult ideas to integrate. In terms of common descent, the idea of change in living things—initially viewed as not possible or the result of a proximate cause and essentialist cognitive bias—transitions to a developmental analogy, i.e. change results from innate potential like growth and metamorphosis, and then to an evolutionary explanation. Learners with a greater understanding of biological change are more likely to accept common descent regardless of age, parental belief, etc.. Therefore, needs-based reasoning and viewing change as developmental serve as transitional concepts between essentialist and intentional ideas and evolutionary explanations (Evans, et al., 2012; Herrmann, French, DeHart, & Rosengren, 2013).

Studies of undergraduates and high school students have found that students with weak biology backgrounds perform poorly and are likely to make incorrect inferences using common ancestry and evolutionary relatedness, particularly for taxa with which they are more familiar (Evans, et al., 2012; Phillips, et al., 2010). One study found that students with some biology experience (who likely had some prior exposure to trees) were less likely to guess than novices when asked questions, but were more likely to use intuitive reasoning such as viewing evolution as a linear process (Catley, et al., 2012)—so while their tree reading skills improved, a linear evolutionary narrative was more common. Additionally, Ainsworth and Saffer (2013) found that some issues related to tree reading such as node rotation and including humans in cladograms—well documented issues with adult learners—did not appear to impact tree reasoning in young children. This suggests that a better understanding of the relationship(s) between tree design, interpretation and explanatory narratives across different age groups would be informative.

In a study of phylogeny graphics, Evans et al. (2010) investigated museum visitors ideas and explanations of graphic panels in the *Explore Evolution* exhibit with different age groups (11-13 years, 14-18 years, and adults) as well as evolutionary biologists. *Explore Evolution* features the work of scientists who are investigating evolution in seven different organisms; four displays include panels with evolutionary graphics (Human and Chimp, Hawaiian Fruit Fly, HIV, Whale). The graphics have different formats: the human/chimp and fly are cladograms, diagrams that depict common ancestry and the pattern of relationships between taxa (but have different geometries; rectangular and angled, respectively); HIV is represented in a phylogram, where differing branch lengths represents some measure of change; and the Whale graphic is the featured researcher's own representation of relationships.

Evans et al. found that participant responses included ideas about common ancestry, time, and relationships between species for all graphics. In particular, the whale evolution graphic conveyed a clear message about relationships and common descent, and elicited the more sophisticated needs-based explanations. Novices used both intuitive reasoning about change, i.e. evolutionary change as a developmental process, and evolutionary reasoning in their explanations, particularly for this representation. Compared to the cladograms, this simplified tree conveys a clear message about relationships; however, the authors (op cit.) note that it may be more likely to elicit the intuitive idea that evolutionary change is like developmental change, especially to younger and/or less expert museum visitors. They also suggest that tree graphics in general may impede an understanding of natural selection, perhaps because they typically show a single member of each taxon, and so do not facilitate thinking about variation within populations, suggesting that the unit of evolutionary change is the individual.

The particular element of interest in the whale graphic in terms of my study is the placement of named taxa along an internal branch. The linear depiction of evolutionary history—taxa arranged sequentially in a row along a time scale—is thought to be problematic and to reinforce the intuitive conception of anagenesis, i.e. the idea that speciation occurs through a transformation process in which one species turns into another. Portrayal of ancestor–descendant or anagenic relationships violates the principle of cladogenesis, speciation occurring through splits in parent populations (Catley & Novick, 2008).

Prior work with university students has found that linear depictions of taxa in trees are more likely to yield inaccurate conceptions of evolutionary history such as anagenic and teleological interpretations and explanations than branching diagrams (Catley, Novick, & Shade, 2010; Novick, Shade, & Catley, 2010b). Therefore, I would anticipate that if all taxa in the whale graphic described earlier were placed on separate branches and at terminal branch points, it would elicit less intuitive and more evolutionary reasoning, and that it would be easier to correctly read and interpret the diagram. I investigated this question in my study; along with what role this design element might play within a developmental framework (i.e. learning progression), and the association between narrative explanations and diagrammatic interpretation. The potential impact, if any, on questionnaire performance depending on the type of question would also be of interest as previous work has found that *relation* questions (i.e. which taxa are closely related) are more difficult than those about *common ancestors* (i.e. which two taxa shared a common ancestor most recently), *features* (i.e. what features does x have) and *animals* (i.e. these animals have x feature) (Ainsworth & Saffer, 2013; Evans, et al., 2012; Halverson, et al., 2011; Novick, Shade, & Catley, 2010a).

CHAPTER III: THEORETICAL FRAMEWORK

Constructivism

Informal learning opportunities play an important role in science learning, and museum visitation supports and extends lifelong science learning (National Research Council, 2009). Museum visitors are active agents, building on what they already know to create new meaning from their experiences (Hein, 1998) and placing them within the narratives that they have constructed for themselves. This constructivist perspective—that knowledge and how it is obtained is dependent on the learner—forms the foundation of learning research in informal settings (D. Anderson, Lucas, & Ginns, 2003; Falk & Dierking, 1992). For example, Falk and Dierking (2000) advocate a contextual model of learning as a framework for thinking about learning in free-choice settings, which draws from constructivist, cognitive and sociocultural theories. In essence, that learning is a process of interactions between an individual's personal, sociocultural and physical contexts over time, all of which change throughout an individual's lifetime.

Difficulties with understanding evolutionary ideas result from complex interactions between: (1) developmental constraints/cognitive biases of essentialism (Gelman, 2003, 2004; Gelman & Rhodes, 2012; Kelemen, 2012), teleology (design-based) and intentional reasoning (Evans, 2008; Kelemen, 2012; Sinatra, Brem, & Evans, 2008); (2) prior knowledge and naïve biology theories (Coley & Muratore, 2012; Wellman & Gelman, 1992), which reflect cultural models from science, religion and local ecological factors (Medin & Atran, 2004; Poling & Evans, 2004); (3) ontology and epistemic beliefs (Chi, Kristensen, & Roscoe, 2012; Ferrari & Chi, 1998); as well as (4) emotion and motivation (Brem, Ranney, & Schindel, 2003). In other words, knowledge and epistemic beliefs, as well as cognitive disposition all play roles in the acceptance and understanding of evolution, particularly with regard to humans, and knowledge of the ideas and content themselves does not necessarily translate into acceptance (Sinatra, et al., 2003).

Furthermore, these interpretations and understandings are situated within a cultural context and reflect the broader patterns that predominate in the wider culture (Doering & Pekarik, 1996). Cultural narratives about science and evolution—whether scientifically accurate or not—are powerful and persistent (Beer, 1983; Hayles, 2001, 1995; Landau, 1984; Rudolph & Stewart, 1998; van Dijk & Kattmann, 2009) and many of these have become ubiquitous and entrenched (Scott, 2007). Perceptions and portrayal of evolution in museums often reflect common anthropological imagery (Scott, 2007), and tree diagrams need to be considered within this broader context.

While museum patrons are generally well educated (Korn, 1995) and accepting of evolution (Storksdieck & Stein, 2006), studies have found that people tend to use intuitive reasoning patterns when they are outside of a formal learning environment (Evans, et al., 2006). Furthermore, research on visitors' explanations of evolutionary scenarios found that all visitors use mixed reasoning patterns (novice naturalistic, informed naturalistic, and creationist), and the pattern used and interpretation of relationships varies by organisms—which in some cases reflects using prior experience and existing ideas about organisms to determine relatedness rather than the branching pattern or characters in the trees (Ainsworth & Saffer, 2013; Dodick, 2010; Evans, et al., 2006; Novick & Catley, 2014; Phillips, et al., 2010; Spiegel, et al., 2006).

Typically misinterpretations and misunderstandings about evolution (and other topics) are referred to as *misconceptions*. However, many of these "wrong" ideas are actually perfectly sound ways of reasoning that learners apply in the wrong situation or in an inappropriate way

(Olson, 2011). In other words, common explanations (such as change resulting from intentional choice, i.e. an organism *decides* to change) work perfectly well for many everyday situations, but these explanations are not helpful for thinking about evolutionary change, and so are more accurately thought of as *intuitive* interpretations.

Tree reading and interpretation also reflect developmental and cognitive elements that are influenced by visual representation. As schematic diagrams, evolutionary trees depict abstract structure, and so rely on learned conventions to transform the graphic elements into a representation of abstract concepts (DuFour-Janvier, et al., 1987; Hegarty, et al., 1991; Novick, 2006(b); Novick, et al., 2010a; Novick, Stull, & Catley, 2012). Visual reasoning requires the use of spatial elements to highlight conceptual relations and to represent meaning (Bauer & Johnson-Laird, 1993; Gattis, 2004; Gattis & Holyoak, 1996; Glenberg & Langston, 1992; Koedinger & Anderson, 1990; Larkin & Simon, 1987).

Mental Models/Explanatory Frameworks

A complex range of factors influences museum visitors' mental models or explanatory frameworks about evolution, which in turn impacts their interpretation of tree graphics as representations of evolutionary ideas and concepts. A mental model is a conceptual system that represents the physical system that is being reasoned about, i.e. an organized internal representation of a concept or system of concepts (Gentner & Stevens, 1983), and these models interact with other representations, such as diagrams and graphics, during the reasoning process (Nersessian, 2008). The definition of mental model is variable with some scholars opting to use the term explanatory framework, schema or conceptual ecology; although not all researchers consider them to be them to be equivalent terms (Nersessian, 2008). I use the terms mental models and explanatory frameworks, common in the education research literature, as essentially abstractions, idealized and schematic in nature that represent a physical situation that has a suite of objects, entities and processes associated with it—which encompasses prior knowledge, analogies, metaphors, and ontological and epistemological commitments.

Mental models are of interest in terms of their role in conceptual change, specifically their relationship to understanding novice and alternative concepts as well as exploring potential strategies for supporting change such as addressing flawed models or adding to and filling gaps in knowledge (Chi, 2008), which is of interest to science education researchers and practitioners (Carey, 2000; Duit, 2003; Treagust & Duit, 2008). Robust misconceptions—such as ones about evolution—are persistent and particularly resistant to change. Several studies have explored the idea of mental models/explanatory framework to investigate student reasoning about evolution and conceptual change (Beggrow & Nehm, 2012; Demastes, Good, & Peebles, 1995, 1996; Ferrari & Chi, 1998). As an example of how mental models might relate to ideas about conceptual change, Chi et al. (2012) propose that robust misconceptions (e.g. natural selection) are particularly resistant to change because of a 'mis-activation' of a direct causal rather than an emergent causal schema—essentially, a well-developed schema is activated that is inappropriate for the science concepts being explored, and the learner is unaware that they have an inappropriate schema.

A diversity of factors influences these explanatory frameworks or mental models and these need to be considered as researchers explore how to support shifts in learners towards more accurate/appropriate thinking about science concepts or changes in models. Perspectives on conceptual change include epistemological ones, which emphasize a learner's dissatisfaction with existing conceptions; ontological or the way in which learners view reality (e.g. ideas about the categories and nature of materials); as well as diverse affective variables such as the impact of social situations, interest and motivation (e.g. socio-cultural variables).

Many scholars endorse the need for a multidimensional approach to exploring conceptual change learning and teaching about evolution (Sinatra, et al., 2008; Treagust & Duit, 2008, 2009), and multiple studies that have explored epistemological and affective factors in evolutionary learning have found complex relationships among knowledge, understanding, acceptance of and perceptions about evolution and personality, identity and motivation of students and teachers (Athanasiou & Papadopoulou, 2012; Brem, et al., 2003; Clores & Limjap, 2006; Griffith & Brem, 2004; Hawley, Short, McCune, Osman, & Little, 2011; Hokayem & BouJaoude, 2008; Sinatra, et al., 2003).

In terms of ontological perspective, researchers (Chi, Kristensen, et al., 2012; Ferrari & Chi, 1998) have proposed that difficulty in understanding the evolutionary process, specifically natural selection, results from ontological category errors in which natural selection is viewed as a direct rather than emergent process, and an 'event' process category (and its attributes) is applied rather than an 'equilibrium' one. The idea is that novices mis-apply event process characteristics that have distinct actions, a sequential order and are goal-directed to thinking about natural selection, when an equilibrium process, which is non-sequential with ongoing, simultaneous actions, is more appropriate. Therefore, promoting a more appropriate ontological description can facilitate conceptual change; although others (Gupta, Hammer, & Redish, 2010) suggest a more dynamic view of ontology and note that the use of mixed ontologies is common in both novices and experts.

My study explored visitors' conceptions or mental models of relationships and what is depicted in evolutionary trees in an effort to better understand the role of graphic depictions in communicating about evolutionary relationships, with the aim of finding ways to support and facilitate a transition from intuitive reasoning to a more scientific one. A qualitative approach is appropriate given the constructivist framework and the complexity of elements that influence visitors' ideas about evolution, and their interpretation and understanding of phylogenetic tree graphics specifically. A qualitative study attempts to gain a deeper understanding of such complexity (Denzin & Lincoln, 2008). This work will build upon and integrate previous research on how phylogenetic trees are interpreted and understood (Catley, et al., 2012; Evans, et al., 2012); how museums present evolution and tree diagrams (Diamond & Kociolek, 2012; Diamond & Scotchmoor, 2006; MacDonald & Wiley, 2012; Novick, et al., in press); and the development of evolutionary thinking in visitors (Diamond, et al., 2012; Evans, 2008).

CHAPTER IV: METHODOLOGY

This qualitative study used a case study methodology, specifically a multiple-case study strategy (Stake, 1995; Yin, 2003). The emphasis on context and a naturalistic setting for this qualitative research lends itself to a case study approach. In addition, case studies are appropriate for in-depth investigations that involve detailed descriptions and analysis of cases, and are philosophically grounded in a constructivist perspective (Baxter & Jack, 2008; Creswell, 2013).

The goal of my study was to explore potential relationships between a particular design element—linear versus branching depiction—and visitors' conceptions and reading of a tree graphic, and to compare cases. The explanatory focus of this study and its context within an informal museum experience fits with a case study approach. This was accomplished through a series of studies with the unit of analysis or *case* being the interaction with an individual museum visitor (i.e. data collection experience). The *cases* in this study are bounded by time and engagement, as well as the activity and context (Creswell, 2013; Merriam, 2009; Yin, 2003).

Case studies facilitate exploration using a variety of data sources. Indeed a critical element of case study is the use of multiple data sources such as documentation, interviews, observations, etc. (Creswell, 1998, 2013; Stake, 1995; Yin, 2003). As noted by Baxter & Jack (2008), a unique quality of case study research is its collection and integration of quantitative data to gain a more holistic understanding, which I feel is a particular strength of this methodology given the topic under investigation.

Therefore, I chose to use a case study approach due to its emphasis on context, focus on deep descriptive analysis and the use of multiple sources of data to analyze multiple cases (Creswell, 2013), in an effort to gain a more detailed understanding about visitors' ideas and better capture the varied conceptions that individuals bring with them.

Research Setting

I conducted my research at the University of Kansas (KU) Natural History Museum on the main KU campus in Lawrence, Kansas. The museum is one of six units of the KU Biodiversity Institute, a national leader in biodiversity research and graduate education with almost 9 million specimens in its collections.

The Natural History Museum houses 50,000 square feet of exhibits on four floors, including the Panorama of North American Wildlife, one of the largest and oldest dioramas in the world; the flora and fauna of the Great Plains; vertebrate and invertebrate fossils; live snakes and bees; and a changing exhibits gallery currently housing the long-term *Explore Evolution* exhibit (NSF Grant No. 0229294).

I used a separate interview space, the public education classroom (304/305 Dyche Hall), located outside of the public gallery space for study purposes. My study received Institutional Review Board (IRB) approval in August 2013; KU HSCL IRB STUDY00000088.

Participant Recruitment

Twenty participants were recruited for this study: six in each of the two youngest age groups (11-13 years or middle school age, and 14-18 years or high school aged), and eight adults. Half of each group saw a tree graphic with linear depictions of taxa, half a redesigned graphic with a branched depiction (Table **2**). Evans and others (2000, 2001; Evans, Spiegel, et al., 2010) found that while children are more likely to use intuitive explanations, adults and high school/college aged students continue to use intuitive reasoning for thinking about evolution. I selected the age ranges in this study to allow for a direct comparison to a 2010 Evans et al. study of tree graphics, and to further inform our understanding of the successively more sophisticated ways of reasoning about evolution, i.e. a proposed learning progression with common ancestry and descent, which indicates that the patterns seen in adults—creationist, evolutionary and mixed—appears at 10-12 years of age, as well as the potential role of graphic depiction in supporting more scientific explanations.

I initially proposed a sample size of between three and five participants in each group to try and identify patterns or themes within and between groups; additional participants from all or selected groups would have been recruited if necessary to clarify patterns, further refine groupings (e.g. age distribution), etc.. I determined the number of cases on the basis of data saturation regarding the particular research questions under investigation as part of the iterative data collection and analysis process. I summarize study participants and provide a description or profile of each case, i.e. individual participant in Appendix D.

Table 2 Summary of participant data collection (n=20).

	Age Group		
Tree Design	11-13	14-18	Adult
Linear	3	3	4
Branched	3	3	4

I used a convenience sampling approach in this study to target individuals that had visited the KU Natural History Museum (Patton, 1987). Participants were to reflect regular museum visitors, and so my recruitment focused on previous museum visitors such as members and former program attendees and their families that had visited and participated in museum activities. Prior research demonstrates that tree thinking is not easy; even well-educated undergraduate students struggle with the spatial relationships as well as the underlying evolutionary concepts (Catley, et al., 2012). Although museum visitors likely are to be better educated than the general population and to be interested in natural history (Korn, 1995), most are novices with only a third having a reasonable understanding of evolution (Evans, et al., 2006).

Previous studies have found a pervasive use of mixed explanatory frameworks to interpret evolutionary change among museum visitors, which demonstrates that some conceptual biases apparent in early childhood persist in adult populations, even highly educated populations interested in natural history (Evans, 2001; Evans, Legare, & Rosengren, 2011; Evans, Spiegel, et al., 2010). Focusing on museum visitors is an important first step if we hope to create graphics that the general population, who might be less interested, less experienced or less knowledgeable, can grasp.

I sent recruitment letters to potential participants identified using three information sources: summer camp participants from 2009 to 2013, 2010 and 2012 adult workshop participants, and a museum member list. A standard recruitment letter was sent with a customized note to each source group indicating why I was contacting them, e.g. *You are receiving this letter because in the past your child participated in science summer camps at the KU Natural History Museum. I am writing to you today to ask for your child's, yours or other family members' participation in a study about graphics used in museum exhibits. The enclosed letter provides additional details about the study*.

I culled all the data sources and removed anyone outside of the local area (e.g. they needed to have a Lawrence address, a KU department address, or live within a 10 mile radius of the museum), and I eliminated individuals if they worked or otherwise had a formal affiliation with the museum other than as a member (e.g. staff, museum board member). For summer camps, I sent letters to the parent/guardian of participants whose parent/guardian was also listed as the payee for the camp as this is the address data collected for mailing purposes and so reflects the participant's address (which is often not the case when grandparents or others are paying for camps), and they represent the person that can authorize the participation of minor in the study.

The museum member list was more challenging to work with since the program is now managed by the university endowment association, which places strict limits on the use of these lists outside of their office. Therefore, Jen Humphrey, communications director at KU Natural History Museum provided me with a current member list up to April 2012 (when the endowment association took over the membership program). I cross-referenced members with a renewal date in 2012, 2013 or 2014 with a donor list of $40 or more (the minimum membership category) for the previous 18 months up to the end of 2013. This edited list was then cross-referenced with the two other lists. For summer camps, I removed duplicates from the member list since the camp experience represents a more direct and close connection with these individuals. For adult workshops, I removed duplicates on this list since membership represents the more recent relationship with these individuals. Finally, the communications director (now director of external affairs) reviewed the edited member list and she removed several participants for various reasons such as being former board members.

One hundred and thirty-six recruitment letters were sent (summer camps 73; adult workshops 11; members 52); seven of which were returned as undeliverable, for a total of 129 potentially valid contacts. Fourteen responses resulted in twenty individual participants or cases, giving a response rate of 10.9% and 15.5% respectively. This resulted in several members of the same family participating in the study; their relationships are noted in the individual summaries (Appendix D). Although this potentially narrows the diversity of cases represented, I felt it provided an opportunity to compare and contrast responses among family members by age and/or tree design.

Data Collection Methods

I collected study data at the natural history museum in the public education classroom. To assess the impact of a linear versus branched depiction of taxa in trees on evolutionary narratives, and tree reading and interpretation I used semi-structured interviews and questionnaires. These techniques were selected for their strengths in providing context and usefulness in describing complex situations (Marshall & Rossman, 2006).

Two versions of a whale tree graphic were used to investigate participants' responses on what they thought the graphic is about, and their ability to answer questions about taxa and relationships depicted in the tree. One version was the existing whale graphic that includes a linear depiction of taxa from the *Explore Evolution* exhibit (described earlier) minus any titles and explanatory text (Appendix A). The redesigned version moved taxa located along branches to separate, individual branches at terminal branch points (Appendix B). Half of participants in each age group used the linear version, the other half the branched version.

The whale graphic is described by the Principle Investigator for the *Explore Evolution* project as the researcher's representation of relationships, and is intended to be more distant from a direct depiction of the phylogenetic relationships (Diamond, 2013)—such as a representation of the stages of cetacean evolution. It uses branching, however, to separate some lineages and labels a shared ancestor at the root of the tree reflecting ideas of common ancestry and descent—and therefore is appropriately thought of as evolutionary tree, and is indeed interpreted as such by visitors (see previous discussion of Evans et al., 2010). Furthermore, the redesigned version of the graphic is consistent with published whale phylogeny graphics (for example, http://evolution.berkeley.edu/evolibrary/article/evograms_03).

Strategy: Interview

Participants were shown a large-scale version of one of the graphics and asked eight questions; follow up or clarification questions were asked where necessary.

Question 1 – What do you think this picture is trying to show?

Question 2 – How do you think that happened?

Question 3 – What kinds of things do you see here?

Question 4 – What do you think this picture is trying to show about *Balaenoptera musculus* and *Tursiops truncatus*?

Question 5 – What do you think this picture is trying to show about *Elomeryx* and *Hippopotamus amphibius*?

Question 6 – At one time there was one species of animal (point to Artiodactyl ancestor) and now there are hippopotamuses and baleen whales and toothed whales. How would you explain this?

Question 7 – Is there anything else that you think is interesting about this graphic?

Question 8 – If you had to tell someone about this graphic, what would you tell them?

I recorded participants' verbal and spatial responses (audio and video) during the interview. As an introduction and warm up activity prior to asking questions, I pointed out and named all the animals to help orient and familiarize participants, particularly younger ones, since they are unlikely to be familiar with the scientific names and might struggle with reading them (pronunciations followed the conventions used on http://animals.jrank.org/pages/2566/Pronunciation-Guide-Scientific-Names.html, see also Appendix A).

I used an interview checklist and summary form to keep a record of the participant number (chronological), date, start and end times with a checkbox to confirm receipt of a signed consent form and to indicate whether a youth assent statement needed to be read. This form included the text for introducing the graphic (taxa names) and a short overview of the questionnaire to be read at the end of the interview, a list of the questions with a few lines of empty space for making short notes during the interview itself and while participants were completing the questionnaire. Participants were identified using the following format—participant number (underscore) MMDDYYYY (underscore) age group (underscore) tree format. For example, 001_02042014_1_L was the first participant, interviewed on February 4th, 2014, in the youngest age group and used a linear tree graphic. I recorded the interviews using a Kodak Zi8 video camera on HD1080p as .mov files; a duplicate/backup audio recording was made using Audacity (http://audacity.sourceforge.net/) on a Mac laptop. The video and backup audio files were downloaded onto a Mac computer for transcription purposes.

The many strengths of using interviews and observations (field journal and video recording of interviews in this study) support their use in my research. They foster face-to-face interactions, are useful for exploring participant perspectives, facilitate immediate follow up for clarification of data collected, are flexible and have the capacity to provide context information (Marshall & Rossman, 2006). Although weaknesses include the potential for data to be affected by researcher presence and misinterpretation, I felt this strategy would be helpful in exploring relationship and relatedness conceptions elicited by trees by focusing on the words and actions of participants, and being able to clarify their explanations on the spot (i.e. member checking). Including non-verbal communication data by video recording the interviews, and contextual data by maintaining a field/researcher journal provided important information during the descriptive and interpretative process (Olson, 2011).

Strategy: Questionnaire

Participants completed a post-interview questionnaire with three parts (see Appendix C). Part A is composed of twelve short closed-ended phylogeny related questions (e.g. multiple choice) about the tree; participants were also given a small-scale copy of the tree to use. A large print version (16 point font) was available on request. Questions focused on three ideas: relatedness/relationships, common ancestry, and shared characters/features. Some researchers distinguish between feature and animal questions (Ainsworth & Saffer, 2013), the questions in this study refer to the latter—i.e. what animals would have a particular feature. These were based on or are similar to questions in existing tree quizzes and previous studies such as Baum et al. (2005)—with four questions of each type. Part B collected general demographic data as part of the questionnaire such as sex, age, racial category, ethnicity and education level; personal identifying information was not collected. Part C of the questionnaire asked several more general evolution questions to explore participants' ideas about origins and support of evolution, taken from Spiegel et al. (2012).

Questionnaires are easy to administer, provide an easy basis for establishing generalizability and lend themselves to statistical analysis (Marshall & Rossman, 2006). Incorporating quantitative elements into data collection and analysis is a strength of case studies, it provided an important point of triangulation for data, and allowed the findings to be more readily compared and contrasted with other studies.

Responses to the questionnaire questions were of interest in terms of if and/or how they relate to explanations given during the interview and as a source of potential patterns in terms of responses that varied by tree format or age group. Patterns in whether questionnaire answers aligned or were consistent with interpretations provided during the interview, and whether performance on some or all questions differed by tree design could suggest a congruence or distinction between narrative and reading tasks.

Data Management and Analysis

Data handling procedures are described below (Figure 12). I transcribed interviews and observation notes within 48 hours to minimize omissions due to lapses in memory or illegible notes. Interviews were transcribed into Word (Microsoft Word for Mac 2011) using the video file, and the duplicate/backup audio file when manipulation was needed to clarify participant statements (e.g. change tempo, volume). Participant text is identified by the abbreviation ‘P’; ‘I’ identifies my dialogue as interviewer. Transcripts follow a denaturalized format in which participant verbal responses are transcribed verbatim and include short pauses, disjointed points in sentences, emphasis, actions (e.g. laughter), and any paralanguage (e.g. um, er, well). Complete transcripts for all participants are provided in Appendix E.

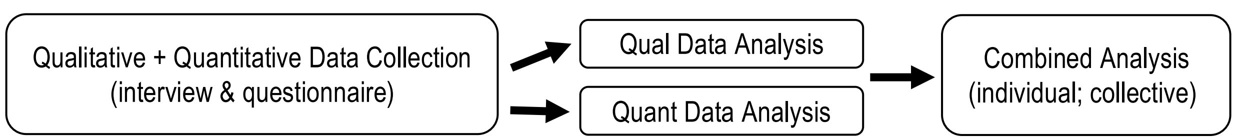

Figure 12 Data Collection and Analysis Sequence.

Preliminary coding categories (i.e. a priori) were based on Evans et al. (2010), and emphasized whether responses included references to relevant evolutionary concepts (common ancestry, time, and relationships), as well as how change related responses are described—e.g. as anagenic (one organism changing into another), and whether the change was referred to as intentional and/or purposeful. I further refined these categories and added new categories by immersing myself in the data (i.e. emergent) through listening to and watching the interviews, multiple readings of transcripts, as well as reviewing notes made on the interview checklist and summary form and journal (Marshall & Rossman, 2006). Table 3 outlines the final interview-coding scheme.

Individual Participant Analysis

I identified and assigned verbal coding categories on a hard copy of the transcript by marking the relevant words or phrases in the text with the letter for that code as outlined in Table 3, along with an associated color and/or symbol (e.g. text underlined in pencil for 'evolution'). The coding was summarized in the left hand margin for each question to facilitate comparison between transcripts. Spatial categories were identified by watching the video several times and then were inserted directly into the relevant parts of the transcript text using squared brackets with the category code and any additional details that I felt were important to note in lower case. As part of the coding process, I referenced any notes made on the interview checklist and summary form, as these reflected elements that stood out to me at the time of the interview.

Verbal and spatial codes initially were entered in an Excel spreadsheet (Microsoft Excel for Mac 2011). Data included participant information (e.g. number, tree format, age group) and codes were recorded by question number for each time a relevant word or comment was used. For example, if the participant used 'evolved' more than once in the same question, this code was recorded multiple times. Questions for which no codes were identified were left blank. The level of explanation for many questions changed during the course of the interview. For example, a response to a question about a specific part of the graphic often transitioned to more general explanations about the graphic or related topics, and some participants were more talkative than others; therefore, assigned codes were condensed into a single table that summarizes participants' references to identified categories. Detailed information about the language used and explanations given for the overall tree and particular parts of the graphic are discussed as part of the results and interpretations.

Table 3 Tree Interview Coding Scheme

<table>
<tr><td>Age Group</td><td>1=11-13; 2=14-18; 3=adult</td></tr>
<tr><td>Tree Format</td><td>1=linear; 2=branched</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2">Questions</td></tr>
<tr><td colspan="2">What do you think this picture is trying to show?
What kinds of things do you see here?
How do you think that happened?
What do you think this picture is trying to show about Balaenoptera musculus and Tursiops truncatus (point to taxa)?
What do you think this picture is trying to show about Elomeryx and Hippopotamus amphibius (point to taxa)?
At one time there was one species of animal (point to Artiodactyl ancestor) and now there are hippopotamuses and baleen whales and toothed whales? How would you explain this?
Is there anything else that you think is interesting about this graphic?
If you had to tell someone about this graphic, what would you tell them?</td></tr>
<tr><td colspan="2">Coding Verbal</td></tr>
<tr><td colspan="2">A. COMMON ANCESTRY – Does the participant mention ancestry, ancestors, common ancestor(s) or refer to early or first versions of taxa? Example: "It's about the ancestry of hippopotamus, baleen whales and toothed whales." or "Um – it looks like an evolutionary tree. It looks like we have the [pause] common ancestor – I guess – down there…"

B. TIME – Does the participant mention time, e.g. refer to the timeline or specific points on the timeline, many years, earlier or later, first? Example: "…branching off starting at 55 million years ago…"

C. RELATIONSHIPS – Does the participant mention relatives, being related or relationship between taxa? Example: "That they are more closely related."

D. CHANGE/ANAGENIC – Does the participant say the graphic shows a transformation from one species/kind/group into another (e.g. one taxa became or turned into another, one is the direct ancestor of another)? Example: "…Elomeryx sort of developed over time and became sort of amphibious."

E. CHANGE/CLADOGENIC – Does the participant say the graphic shows a species/kind/group splitting, separating or dividing? Example: "…they are related animals. That split off from a single ancestor 35 million years ago."

F. FEATURES – Does the participant mention particular features of taxa shown, e.g. compare different organisms? Example: "…have gone from having – legs to seemingly to having fins." or "…well the flipper on this are a little more like hands…"

G. EVOLUTION – Does the participant mention evolution or related terms when talking about the tree? Example: "Um, like the evolution – of the one down here into different species."</td></tr>
</table>

H. CONSTRUCTION – Does the participant talk about how the graphic was put together, e.g. evidence? Example: "…*shows what scientists have uncovered or they've hypothesized or they believe*."

*I. INTERNAL INTENTION/PURPOSE – Does the participant refer to the intention or purpose of taxa? Example: "… *one group chose a different – environment and then the other one chose, uh, maybe the opposite.*"

J. NEED/TELEOLOGICAL – Does the participant refer to need based or a required change? Example: "…*in certain habitats it needs to be able to swim or it needs to able to reach up higher*…"

*K. WANT/TELEOLOGICAL – Does the participant refer to want based change? Example: "*Like, like if it wants to get more water food it can turn more into like an aquatic animal*…"

*L. EXTERNAL FACTOR SUPERNATURAL – Does the participant refer to a supernatural intention or cause, e.g. God? Example: "*I mean, if you – ask a basic question, you know "Did God put us here or not"*."

M. EXTERNAL FACTOR OTHER – Does the participant refer to an external factor or cause, e.g. environment, habitat? Example: "*...change according to their environments, and according to nat, natural disasters and things that happen in nature.*"

N. ESSENTIALIST – Does the participant refer to an inherent or fundamental property of taxa or that they are stable and not changing? Example: "*They're just here…then it goes back to your basic values, if you believe in religion or versus evolution.*"

O. VARIATION – Does the participant talk about differences among individuals in a population? Example: "*...it might be a subtle as a, a trait from generation to generation – you get enough generations and, uh, and then the traits can become much more distinct…*"

P. SELECTION – Does the participant talk about taxa with traits that are favorable or selected for survival or reproduce more? Example: "…*a mutation that occurred and would split off and maybe the Elomeryx was wasn't so suited for survival anymore and went, went, uh, onto become extinct, but the hippopotamus was so it is still alive*."

Q. INHERITANCE – Does the participant refer to traits being passed between generations or change between generations? Example: "*...means they had to adapt to different things. Then as they – had children, then they had to evolve differently and that just kept going on and on…*"

*R**.** CREATIONIST – Does the participant specifically reject or question an evolutionary explanation based on religion? Example: "…*if you – ask a basic question, you know "Did God put us here or not". But, you know, that's a – different level*."

S. ADAPTATION – Does the participant refer to taxa having adaptations or being adapted? Example: "*Um, over time adaptation to environment and, changes in maybe – predators – or, and uh, their food.*"

T. CHANGE OVER TIME – Does the participant talk about change or a rate of change over time? Example: "*..how much of a change can happen in a short amount of time.*" or "*...this is happening over millions of years*."

U. DESCENDANTS – Does the participant refer to descendants (e.g. progeny/offspring/children) or reproduction/procreation? Example: "*…could flourish, and then their babies could flourish…*" * Combined during analysis based on similarities and limited use (K and I; L and R)
Coding Spatial
POINT – Does the participant point to an individual point on the graphic? TRACE – Does the participant connect points on the graphic by following a path, i.e. point at one spot and move continuously along a branch to another point? SPLIT – Does the participant indicate a split, separation or divergence? GESTURE – Does the participant gesture towards the graphic or in close proximity in connection with a particular idea or statement? COMPARE – Does the participant compare items or different parts of the graphic, e.g. use two fingers to measure taxa?

I kept a field/researcher journal for making analytical notes and comments throughout the study including participant recruitment phase, following individual data collection sessions, and during the coding and analysis process. I also recorded any ongoing thoughts and comments about or related to the study on at least a weekly basis. Journal notes were reviewed at least once a month during the data collection and preliminary coding phases of the study; any additional comments or modifying notes were made in different colored ink along with a note indicating the date of these edits. The entries include any technical and logistical issues that arose; any questions and thoughts that came to mind related to participant recruitment and related to interviews and questionnaires based on other interactions (e.g. experiences with other visitors, discussion as part of other tree related projects that I am part of). These notes provided an important check on consistency in terms of trying to convey visitor thinking, and served as a reflection tool to highlight potential biases in my interpretation.

Questionnaire responses were coded according to the scheme outlined in Table **4** and data was entered into SPSS; multiple choice responses were recorded as correct or incorrect and by the particular option selected, to allow for a more detailed consideration of incorrect and partially correct responses. Notes were made directly on the questionnaire to record any thoughts during this process such as a link to previous research, interview statement or other participant responses. Item analysis was considered individually and in groups (e.g. common ancestry questions, relatedness questions). ANOVA tests were run to investigate the statistical significance of any observed differences; given the diversity of participants in terms of age and experience, a conservative alpha value of 0.01 was used.

Table 4 Tree questionnaire coding scheme.

<table>
<tr><th colspan="2">Age Group</th><td colspan="2">1=11-13; 2=14-18; 3=adult</td></tr>
<tr><th colspan="2">Tree Format</th><td colspan="2">1=linear; 2=branched</td></tr>
<tr><td colspan="4"></td></tr>
<tr><th>Part A</th><th>Question type</th><th>Coding</th><th>Correct response*</th></tr>
<tr><td>Question 1</td><td>ancestor</td><td rowspan="12">0=correct
1=incorrect</td><td>d</td></tr>
<tr><td>Question 2</td><td>relationship</td><td>c</td></tr>
<tr><td>Question 3</td><td>character</td><td>a, b, c, d</td></tr>
<tr><td>Question 4</td><td>relationship</td><td>b</td></tr>
<tr><td>Question 5</td><td>ancestor</td><td>a</td></tr>
<tr><td>Question 6</td><td>character</td><td>b, c</td></tr>
<tr><td>Question 7</td><td>relationship</td><td>d</td></tr>
<tr><td>Question 8</td><td>ancestor</td><td>c</td></tr>
<tr><td>Question 9</td><td>character</td><td>c</td></tr>
<tr><td>Question 10</td><td>relationship</td><td>b</td></tr>
<tr><td>Question 11</td><td>ancestor</td><td>b</td></tr>
<tr><td>Question 12</td><td>character</td><td>a, d</td></tr>
<tr><td colspan="4"></td></tr>
<tr><th>Part B</th><th>Coding</th><th>Part C</th><th>Coding</th></tr>
<tr><td>Annual museum visits</td><td>no set values (numerical)</td><td>Origin of insects</td><td rowspan="3">1=disagree
2=mostly disagree
3=neither
4=mostly agree
5=agree</td></tr>
<tr><td>Age</td><td>no set values (numerical)</td><td>Origin of humans</td></tr>
<tr><td>Sex</td><td>1=female
2=male</td><td>Origin of birds</td></tr>
<tr><td>Ethnic category</td><td>1=Hispanic or Latino/a
2=Not Hispanic or Latino/a</td><td>Scientists study evolution</td><td>1=not important
2=a little</td></tr>
</table>

Racial category	1=White 2=Asian 3=American Indian or Alaska Native 4=Black or African American 5=Native Hawaiian or Other Pacific Islander	Important to know about evolution	important 3=pretty important 4=very important
K-12 grade	no set values (numerical)	Knowledge about evolution	1=not much 2=a little bit 3=some 4=quite a bit 5=a lot
Education level	1=high school 2=undergraduate degree 3=graduate degree		
Area of study	no set values (text)		

* Questions 3, 6, 9 and 12 require selection of all correct options; all others have one correct response.

Raw electronic recordings, the transcripts (Microsoft Word 2011 documents) and any statistical software data files used for analysis were kept in folders that were only accessible through a password-protected computer and were stored or backed up to a secure server. Additional backups made to a portable hard drive, desktop or USB key were encrypted using software (TrueCrypt, http://www.truecrypt.org/). Original questionnaires and all consent documents were kept in a locked drawer.

Combined Individual Participant Analysis

I wrote a combined analysis or synthesis of the interview and questionnaire data for each participant using a narrative format to integrate the verbal and spatial results from the interview with questionnaire responses, as well with any general observations or notes made on the interview checklist and part of journal reflections. Pseudonyms were used for the narrative to facilitate reading and to provide a more personalized context.

The general sequence I followed for each participant was as follows: questionnaire data was entered into SPSS; interview was transcribed; spatial coding was added to the interview transcript; verbal coding of the interview was done; verbal and spatial coding was added to the Excel spreadsheet, and an individual narrative summary was written. Not all steps, however, were completed for individual participants independently. For example, multiple interviews were transcribed or coded during the same session, but were done in the order of participation.

Multiple-Case or Collective Analysis

A combined analysis for multiple participants that considered, compared and contrasted responses by age, tree format, etc. was done for interview and questionnaire data independently and together, as well as referencing the individual combined interview and questionnaire narrative summaries described earlier. A preliminary collective analysis was conducted for participants 001 to 009, which reflected data from at least one linear and one branched tree format for each age group, to identify and explore any themes and patterns. Additional data for participants 010 to 016 were incorporated and emergent themes refined as part of the ongoing analysis process; and the process was repeated once more following the final data collection phase for participants 017 to 020.

Trustworthiness

Evidence of trustworthiness in this qualitative study was assessed in several ways. Dependability and credibility (i.e. whether the study measures what it intends and evaluates the consistency of findings) was facilitated through data collection and analysis strategies. Transferability and confirmability (i.e. whether the study measures what it intends, and its potential value within the broader research context or generalizability) was supported through comparison with extant literature as well as member checking.

Triangulation and Credibility

Triangulation (i.e. dependability) and credibility of the data was facilitated through the use of two data collection strategies (interview and questionnaire), a sample size that reflects data saturation (see participant recruitment section), a multiple stage and iterative analysis process that moved between a fine-grained approach for each case in an effort to gain a sense of the understanding and conceptions of individuals, to a more coarse-grained or broad analysis of the cases collectively, and documentation through a researcher journal. In addition, plausible alternatives and discrepant events were explored and are highlighted in the analysis and interpretation of findings. Using multiple data sources, creating a study database and maintaining a chain of evidence are three principles of collecting case study evidence outlined by Yin (2003). It also addresses the criteria for constructivist qualitative studies of credibility, transferability and confirmability (Denzin & Lincoln, 2008).

Intra-coder reliability for the interviews was assessed by re-coding verbal responses from 20% (n=5) of the transcripts (randomly selected using Excel) and comparing these codes to those identified during the original coding on two separate occasions—the first approximately eight weeks after coding of all transcripts was complete, and then again almost three weeks later—both resulting in a 98.9% coding agreement (Table **5**).

Table 5 Intra-coder reliability (identified verbal code categories outlined in Table 7).

Participant	Codes Identified Agreed	Codes Identified Disagreed	Participant	Codes Identified Agreed	Codes Identified Disagreed
008	19	0	006	19	0
009	18	1	007	19	0
013	19	0	009	19	0
014	19	0	011	19	0
015	19	0	013	18	1
Total	**94**	**1**	**Total**	**94**	**1**
(total agreement)/(total agreement + total disagreement) 94/95 = 0.98 or 98.9%			(total agreement)/(total agreement + total disagreement) 94/95 = 0.98 or 98.9%		

Stakeholder/member checking, in which the findings are checked with participants, was done in the form of restating and/or summarizing individuals' statements as part of the interview process. Member checking through a post-interview follow up with participants was not used in this study for a few reasons including the naturalistic focus of this research in which the case or unit of analysis is the interaction with the individual visitor and so is bounded by the particulars of the data collection experience; i.e. time, activity and context.

More importantly though, is that I felt that subsequent checking was likely to have resulted in confusion rather than clarification (or confirmability) given the conflicted and changeable nature of many participant explanations—which represents an important element of participant responses and the interpretation framework—and would have likely elicited 'corrected' interpretations based on prior or subsequent knowledge and experience (including reflection on the interview experience), particularly in cases where individuals referred to what they have been taught about evolution that often did not match their explanatory narratives. Potential issues and drawbacks with post-interview member checking such as presentation of information and corrected versus clarified responses have been noted by some qualitative researchers (Angen, 2000; Hallett, 2013; Sandelowski, 1993). Detailed descriptions of each individual case (i.e. participant narrative analysis) are provided in Appendix D, complete transcripts are provided in Appendix E, and extensive direct quotes are used throughout the analysis and interpretation chapters in an attempt to credibly reflect visitors' ideas.

Transferability and Confirmability

Transferability and confirmability of the results are supported through the similarity of findings between cases as well the outcomes of prior research. Peer checking was conducted through the presentation of emerging findings at the 2014 NARST (National Association for Research in Science Teaching) Sandra K. Abell poster symposium in Pittsburgh, PA (MacDonald, 2014). Conversations with participating researchers included Laura Novick (Associate Professor, Psychological Sciences, Vanderbilt University) who studies learning with tree diagrams and is a collaborator on tree related grant projects that I have been and am currently part of (e.g. NSF-funded *Understanding the Tree of Life* and IMLS-funded *The Tree Room: Teachings and learning about evolutionary relationships*); preliminary results of my study were shared with her to include as part of a guest lecture.

Researcher Perspective

My educational background is in anthropology and biology; evolutionary biology is a core theme in much of my science teaching, which includes college level courses, outreach initiatives and museum programs. For as long as I can remember I have accepted and endorsed evolution as a central part of understanding the natural world; and while I understand some of the cultural and linguistic factors that result in its rejection by some, I feel that evolution is essential to understanding the world and broader ideas about the nature of science.

I am the Associate Director of Public Programs (formerly Director of Education) at the University of Kansas Natural History Museum and have worked in science education for more than twenty years, much of which has been in informal education settings such as museums or science centers. My prior experience conducting observations and interviews has included structured and unstructured data collection during museum programs and events, and evaluation of museum educators and graduate students teaching in schools and informal settings. This includes the creation and/or administration of surveys/questionnaires with program participants (K-12 teachers and students, adults including university students, parents/guardians and their children); and a primate behavior study as an undergraduate project. My prior experience with formal interviewing in the context of a science education study is as a student during graduate course work.

Evolution can be a challenging topic to teach, and one in which misinterpretation, misunderstanding and poor communication are common. In my capacity as Associate Director of Public Programs, I am occasionally asked to leave out information from education programs related to evolution such as the age of the Earth or mentioning humans in the context of adaptation or the fossil record that a teacher feels is potentially problematic. These requests are never granted, and an explanation of our status as a science institution that presents a scientific understanding of the natural world in our exhibits and programming is provided. Even for programs that have only tangential connections to evolution our policy is that any relevant science question asked by program participants will be responded to in a way that represents scientific thinking. This is consistent with supporting the understanding and teaching of evolution, although not all museums adopt the same approach.

I am from Canada, where the acceptance of evolution amongst the population is higher than in the United States, but I have long been aware of the difficulties with the issue in the US through media coverage, television programming and through my position at the University of Kansas Natural History Museum. As an evolution educator in Kansas, I am acutely aware of the perceptions and stereotypes of Kansas and its relationship with evolutionary biology within this country and internationally; yet from personal experience and awareness of this issue more broadly, I recognize that Kansas is neither unique, nor particularly unusual in its sometimes-tumultuous handling of this science topic in the United States and beyond.

I have been involved with several externally funded tree-related projects (National Science Foundation and Institute of Museum and Library Services). I was a collaborator on the *Explore Evolution* project led by the University of Nebraska State Museum, PI on the *Understanding the Tree of Life* project, Co-PI and outreach lead on the *Euteleost Tree of Life* project, and currently am KU PI on *The Tree Room: Teaching and learning about evolutionary relationships* project led by the University of California Museum of Paleontology. Furthermore, my previous support of and, since July 2013, oversight of the museum's exhibits department since July 2013 has resulted in more tree graphics being incorporated into exhibit labels and in one case to date resulted in a change of specimen layout in relation to the associated tree graphic.

Framework for Interpretation

There are a few elements that need to be considered in interpreting the findings of this exploratory study. There is the potential for the interview to influence questionnaire responses; i.e. it is possible that asking about what the graphic is trying to show and asking about process could impact later answers. Previous studies, however, have found that trees tend to elicit ideas about relationships, but not necessarily evolutionary ones and that many individuals' illustrations of relationships tend to reflect intuitive thinking or common evolutionary folk narratives. In addition, evolutionary ideas or language was used only in the context of restating a participants' response using their own words for clarification when necessary. Therefore, it is reasonable to anticipate that the interview did not have a significant impact on the answers given on the questionnaire, although explicitly talking about the tree in advance will have brought attention to the ideas associated with the graphic.

I am interested in exploring museum visitors' conceptions of evolutionary trees, how they reflect conceptual frameworks, relate to cognitive constraints and to popular social/cultural narratives about evolution, as well as how we might design trees to support a transition from intuitive reasoning to a more scientific one. Given that the subject is evolution, it is possible that visitors who are uncomfortable with the subject or consider the concept of evolution to be problematic might have declined to participate in this study, and so their perspective about evolutionary scenarios and trees would not be represented. This research, however, was described to the participants as a study about museum graphics and not explicitly identified as being about evolution since participants' ideas of what they think the graphic is about forms part of the research question. The graphics were not referred to as trees, evolutionary trees or phylogenetic trees during the interview or administration of the questionnaire; although, the questionnaire includes questions about common ancestry, relatedness and shared characters, all participants described the graphic as being about evolution prior to completing the questionnaire. Furthermore, not everyone makes a connection between natural history museums and evolution (MacDonald, 2006 unpublished).

Visitors might have declined to participate or drop out at any point in the process for a multitude of reasons—which may or may not be related to their views about evolution—and so unless they specified a reason, any anti-evolution stance cannot be determined. In this study, one participant expressed a creationist perspective, alongside more scientifically-based explanations, and disagreed (mostly) with evolution as an explanation for the origin of humans and birds. All other participants 'agreed' with origin statements for insects, birds and humans, but their level of agreement varied by individual and taxa.

While some overall patterns are recognized and generalizations can be made about the demographics of museum visitors in the broadest sense, museum patrons do not represent a homogenous group, and complex factors influence visitor learning outcomes (Falk & Dierking, 2000; Storksdieck & Falk, 2005). Therefore, to a certain extent this study is an exploration of how these particular visitors with their individual prior knowledge and experience engage with, interpret and understand evolutionary tree graphics with particular design elements. Common narratives about evolution, as well as diagrammatic misinterpretations and misunderstanding, however, have been identified in other studies, and part C of the questionnaire collected general demographic data and participants' broad conceptions about evolution that was considered during analysis.

Research Timeline

Participant recruitment and data collection began in early spring 2014 and continued through mid-April; data analysis was conducted through the spring and summer, with ongoing analysis and writing in fall 2014 (Table 6).

Table 6 Timeline of Study.

	Jan-Feb (2014)	Feb-April (2014)	April-May (2014)	May-Sept (2014)
Participant Recruitment				
Data Collection (including interview transcription and questionnaire data entry)				
Develop/Refine Coding Scheme for Interviews				
Interview Coding & Analysis				
Ongoing Analysis & Writing				

CHAPTER V: FINDINGS

My exploratory study sought to investigate the influence of tree graphic design—specifically linear versus branching depictions of taxa—on visitors' interpretation and understanding across ages using a multiple-case study strategy. Specific research questions explored were: (1) How does taxa placement as a result of linear or branched depiction influence narratives about phylogenetic trees?; (2) How does taxa placement as a result of linear or branched depiction affect the reading and interpretation of trees?; and (3) Do the relationships between tree design, narratives and interpretation vary by age?

The results of this study support previous work that found that tree graphics support visitor thinking about common descent and the idea that change can occur, and that most participants use mixed reasoning (i.e. novice/intuitive and naturalistic/evolutionary) in their explanations (Evans, Spiegel, et al., 2010). There was little difference in terms of questionnaire performance by age group; members of the youngest group (aged 11-13), however, were less likely to provide much detail or to incorporate evolutionary ideas (e.g. variation, selection, inheritance, time) into their explanations.

Across all age groups, the study findings indicate that different taxa depictions—linear versus branched—elicit qualitatively different narratives and explanations about the relationships between the taxa across. Specifically, branched depictions appear to support more scientifically appropriate understandings and explanations (i.e. evolutionary change is not a linear transformation from change of one kind into another) about the relationships between taxa and the evolutionary change process. The role of graphic design on tree reading and interpretation, as indicated by questionnaire response, was highly variable across ages and tree formats; although branched tree users had higher scores overall, and appeared to perform better on ancestor questions that involve identifying which two taxa share a common ancestor most recently. The questionnaire data lend further support to, and extend, previous work on tree reading challenges (e.g. Ainsworth & Saffer, 2013; Baum, et al., 2005; Halverson, et al., 2011). Overall, the study results highlight several patterns of interest for future studies.

I present a summary of the interview and questionnaire findings in this chapter. A discussion of my interpretations follows in Chapter VI, and their potential implications for future research and science education practice in Chapter VII. Direct quotes from participant interviews are used extensively (age, participant number and tree format are provided); spatial coding information is included where necessary to provide context or where I felt it was particularly informative.

Participant Demographics

Twenty participants took part in this study; six each in age groups 1 (11-13) and 2 (14-18), eight in age group 3 (adults). They ranged from eleven to fifty-three years of age with an annual museum visitation rate of two to more than thirty. Most participants self-reported as White and non-Hispanic/Latino, other identities reported were: one adult White and Hispanic/Latino; one adult Asian and non-Hispanic/Latino; one youth White and Asian of Hispanic/Latino ethnicity; and one youth who identified as White and opted for 'don't know' for ethnicity following a brief conversation (see Appendix D for participant case summaries).

Tree Graphic Interview – General Themes

Overall, both linear and branched versions of the tree graphic elicited ideas of common ancestry, relationships and 'change of kind' (see Figure **13** for whale graphics). One general theme that emerged with regard to the whale graphic was how different the taxa are and how much change had occurred over time—typically participants referred to the significant change from the Artiodactyl ancestor to hippos on the left and baleen and toothed whales on the right, as well as how much the three extant terminal taxa (*Balaenoptera musculus*, *Tursiops truncatus* and *Hippopotamus amphibius*) differ from each other.

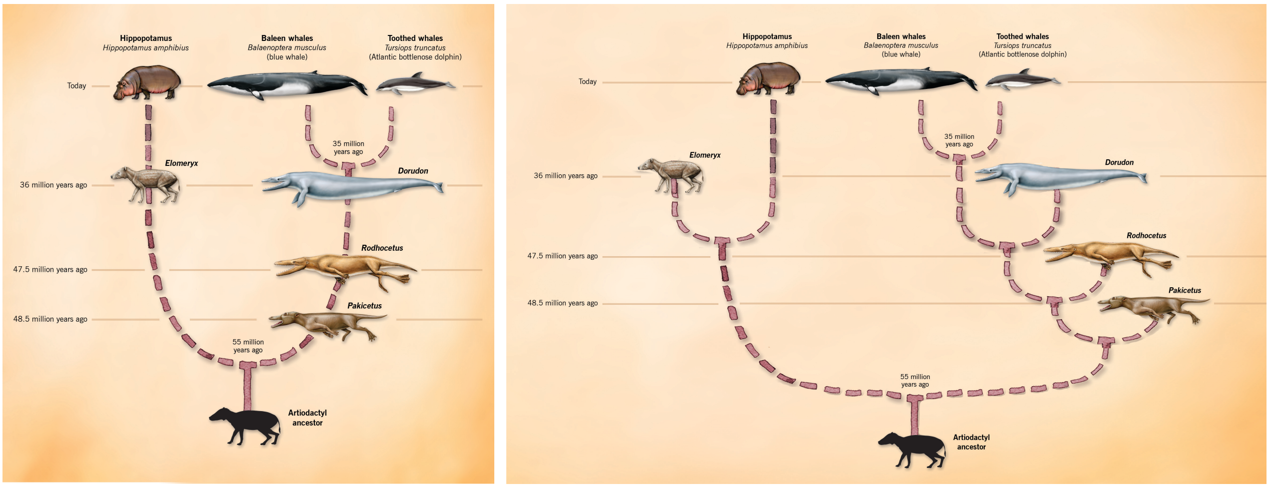

Figure 13 Whale tree graphics (left linear; right branched).

For example, Judy (aged 42, 004, branched tree) commented on the amount of time that passed for such dramatic change to have occurred, "I think that 55 million years ago is a long time. So [pause] you know [pause] they are different [pause] and it's taken 55 million years for them to look so different. I think that's impressive." Whereas Camilla (aged 35, 006, branched tree) felt that a significant change had occurred over a relatively short period of time

> …but I think looking at this ancestor from 55 million years ago to *Elomeryx* they look much much much more – I mean they almost look the same, so I think it's showing how much of a change can happen in a short amount of time, relatively short amount of time.

Melissa (aged 17, 007, branched tree) commented on how such different animals share the same ancestor. "I think it's definitely interesting how, um, even – how even though, the, uh, hippopotamus and baleen whales are – they are all – from the same creatures they ended up in totally different areas."

Several participants noted the absence of taxa on the left branch of the graphic (hippo) compared to the right branch and wondered whether fewer taxa meant an absence of evidence (e.g. gaps in the fossil record) or that little or no change had occurred between the Artiodactyl ancestor, and *Elomeryx* and *Hippopotamus amphibius*. Mary (aged 41, 008, linear tree) said of the few taxa on the left branch,

> I'm surprised there's not more graphics here though [point left hand finger at empty part of left branch] – it's kinda this big jump from here to here [point at Artiodactyl ancestor, then *Elomeryx*].

She also noted the similarity between the Artiodactyl ancestor and *Elomeryx*, and suggested that "…maybe there wasn't – a lot of evolution there [rising tone]."

In fact, Camilla (006, quoted earlier) changed her interpretation of the relatively sparse left branch during the interview. At first, she considered the few taxa shown as reflecting a gap of information, either known or presented.

> …the animals on the right side [gesture at baleen and toothed whales], see, you know, their ancestors [gesture at extinct taxa down along right side], how they evolved. And then, um, a big leap here on the bottom [surprise] – so I assume that there is a whole bunch of animals not shown [gesture up left side from bottom of graphic].

Later, she noted the similarity between the Artiodactyl ancestor and *Elomeryx* and thought it was indicative of how little change had occurred "…it's not that there's a whole bunch of things missing, it's that it had not changed." When asked about more specifically about which taxa she was comparing in terms of change—i.e. Artiodactyl ancestor and *Elomeryx* compared to *Elomeryx* and *Hippopotamus*—she indicated that there could be other taxa not shown and that they would have appeared similar to *Elomeryx*.

> …if there were an animal illustrating [gesture at middle of graphic] – the, animals in between the ancestor and *Elomeryx* I would expect it to look the same, and so if there was a parallel to each one of these three [gesture with both hands at *Pakicetus*, then move left hand to *Elomeryx*; then point right hand finger at *Pakicetus*, then *Rodhocetus*, *Dorudon*, then *Pakicetus*] I'd expect it to pretty much, pretty much [emphasis] look the same as *Elomeryx* [point at Artiodactyl ancestor, then at one point along the left branch, then *Elomeryx*].

Table 7 summarizes the verbal coding of interviews. Participants clearly thought that the graphic was about evolution, all mentioned ‘evolution’ or some variation of the word (e.g. evolved, evolving) at some point during the interview, often multiple times. One participant (Peter, aged 16, 002, linear tree) identified the graphic as an evolutionary tree. Users of both linear and branched formats in all three age groups, referred to ‘ancestors’ and taxa as being ‘related’ (Code A and C, respectively); although not all participants used these terms. References to the environment (Code M) including the habitat in which a taxon would be found was mentioned by all but two participants, both in terms of where the taxa depicted on the left and right branches of the tree currently live or would have lived, as well as in the context of change related questions (i.e. the environment as a factor in questions about ‘how’ change occurred).

Time was another common theme that participants referenced in several contexts—sometimes participants highlighted specific time points marked on the graphic and/or the space between these time periods (Code B), other references were more general temporal comments such as describing how change happened over long periods of time (Code T). Other interview coding categories are discussed under *Reasoning Patterns*, and linear or anagenic change (speciation through the transformation of one species into another) versus cladogenic change (speciation through population splitting events) explanations are discussed in the section titled *Linear versus Branched Explanations*.

Reasoning Patterns

Mixed reasoning—incorporating novice/more intuitive and more informed/evolutionary ideas—was found across all age groups and both tree formats (Table 8). The most common pattern of reasoning observed in all age groups was needs-based reasoning in conjunction with some reference to external factors as change agents, typically environmental change. For example, Mary (aged 41, 008, linear tree) “Uh [pause] um – you know, natural selection [laughs] uh, natural selection, they’ve, um, things, eh, different climates evolved different features to help them sort of adapt and survive in their environment [gesture open hands generally].”, and Samantha (aged 53, 011, branched tree) said, “I would imagine that where Artiodactyl, um – lived at some point it needed to, um – in order to survive, it needed to be able to, um, live in water – and in some places it didn’t.”

Some explanations incorporated the idea of taxa having been or becoming separated or divided as a result of changes to the existing environment such as Carol’s (aged 44, 005, linear tree) explanation of the left and right sides of the graphic.

> Um – maybe [pause] the animals [pause] um, kind of drifted away from each [move left and right hands apart] and some started living in a drier environment, where the water kept, level kept going down and, and needed to have, um, land, um – physical structures like feet and lungs and to breathe.

Lucy (aged 14, 012, linear tree) also described change as the result of isolation or separation among ancestors “…different sections of the ancestor getting, separated, or maybe, um, different groups of the ancestor moving into different parts of the world [indistinct] – where they need, um, different traits to survive in different climates.”

A few participants described the change of environment as a result of relocation by the taxa themselves to new areas, such as Megan (aged 11, 001, linear tree) “Well, after there are so many – it – maybe they spread out to different habitats and then different habitats, they require – they require different things.” Ann (aged 11, 009, branched tree) also talked about taxa going to different places “Maybe [pause] – this one [point at hippo] started going somewhere else and travelling – like in another direction and exploring a different place [pause] and then the other, and then it started changing over time,” but she did not know how the change occurred and guessed they ‘got used to’ places. Elliot (aged 11, 016, branched tree) also struggled to explain

Table 7 Interview verbal coding summary by tree format (1 = 11-13 years old; 2 = 14-18; 3 = adults).

Categories	Linear Tree Format										Branched Tree Format									
	001	010	017	002	012	018	003	005	008	013	009	016	020	007	015	019	004	006	011	014
Ancestor (A)	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓
Time (B)	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
Relationship (C)		✓		✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓
Change/Anagenic (D)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Change/Cladogenic (E)	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
Feature (F)	✓		✓				✓	✓	✓			✓		✓			✓			
Evolution (G)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tree Construction (H)							✓	✓												
Internal Intention (K)/Want (I)			✓													✓				
Need/Teleological (J)	✓	✓	✓		✓	✓		✓	✓			✓			✓	✓			✓	✓
External Factor (supernatural) (L)/ Creationist (R)								✓												
External Factor (environment) (M)	✓	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Essentialist (N)								✓												
Variation (O)				✓			✓													
Selection (P)				✓			✓		✓							✓				
Inheritance (Q)				✓			✓		✓			✓								
Adaptation (S)		✓						✓	✓			✓					✓	✓		✓
Change Over Time (T)		✓		✓		✓	✓	✓	✓		✓	✓	✓	✓	✓		✓	✓		
Descendants (U)							✓		✓			✓					✓		✓	
Age Group	1	1	1	2	2	2	3	3	3	3	1	1	1	2	2	2	3	3	3	3

‘how’ change might have occurred, but during later follow up questions said she thought that the environment probably changed and this ‘made them adapt’.

Two participants specifically indicated that this new environment was by the taxon’s choice. Michael (aged 11, 017, linear tree) explained that one group of the ancestor [Artiodactyl ancestor] “…chose a different – environment and then the other one chose, uh, maybe the opposite environment…” Later he explained that one group travelled to the water, another to the land—and confirmed the role of choice in environmental change when asked if he thought they chose to do that, “Mm-hmm. [pause] Well – may, maybe there was some sort of natural disaster, but mostly likely they would have chose it.” Daniel (aged 15, 019, branched tree) referred to natural selection and geographic isolation in terms of gaining features to help animals survive, noting that the best fit won’t die off—but also referred to ‘want’ in the context of a different environment as well as organismal change “….maybe there’s a lot more aquatic animals that they could eat, so they learn to swim more and they develop that so that they could get easier food.”

In terms of more informed reasoning, specifically the use of variation, inheritance, selection and time (VIST principles), most participants made references to time within the framework of change occurring over time and/or rates of change (e.g. rapid or slow change). Only a few participants, primarily in age groups 2 and 3 (14-18 and adults, respectively), mentioned other VIST ideas such as variation in traits or features among individuals or groups, and selection in the context of differential survival or reproduction. For example, Peter (aged 16, 002, linear tree) explained how there are now hippos and whales when there was previously one species of animal (Artiodactyl ancestor) the following way.

Table 8 Participant reasoning by age group, then tree format. (Variation – differences among individuals/groups; Inheritance – traits being passed between generations; Selection – taxa with traits that are favorable (or not) for survival; Time – change over time, including rate of change.)

#	Age Group	Tree Format	Want/Choice-based reasoning	Needs-based reasoning	External Factors (e.g. environment)	Variation	Inheritance	Selection	Time
001	1	linear		✓	✓				
010	1	linear		✓	✓				✓
017	1	linear	✓[1]	✓[2]	✓				
009	1	branched		*‘got used to’	✓				✓
016	1	branched		✓[3]	✓		✓[6]		✓
020	1	branched			✓				✓
002	2	linear		*‘fit’		✓		✓	✓
012	2	linear		✓	✓				
018	2	linear		✓[4]	✓				✓
007	2	branched			✓				✓
015	2	branched		✓	✓				✓
019	2	branched	✓	✓[5]	✓			✓	
003	3	linear			✓	✓		✓	✓
005	3	linear		✓	✓				✓
008	3	linear		✓	✓	✓	✓	✓	✓
013	3	linear							
004	3	branched		*’adapted to’	✓	✓		✓	✓
006	3	branched			✓				✓
011	3	branched		✓	✓				
014	3	branched		✓	✓				

* Language of interest highlighted, but not coded as ‘need’ as requirement is not explicit; [1] Animals ‘chose’ an environment, which influenced change; [2] ‘had to’ evolve or gain features to help them; [3] ‘made them adapt’; [4] ‘called for’; [5] ‘get features to help them survive’ [6] ‘children and children’s children’, (generations) had to evolve, but were different.

> Um – the, the common ancestor was living in a certain time and something changed or a mutation occurred – and – and probably, probably both of those of those things happened – and the mutation made that select group or that individual more suited so that mutation, you know, developed and – kept, kept happening and so – ah, after a while, you know, they would split off and become two different species [rising pitch].

References to inheritance of traits were rare, but progeny or offspring were occasionally mentioned. Elliot (aged 11, 016, branched tree) referred to change over generations in the broadest sense (e.g. children's children), and while she did not talk about specific traits, her description of how change occurred indicates that changes were passed between generations, although it appears within a Lamarckian sense of acquired traits. For example, "…environments started to change which means they had to adapt to different things. Then as they – had children, then they had to evolve differently and that just kept going on and on until you get something completely different."

Incorporating VIST principles into explanations did not exclude the use of more intuitive or novice needs-based reasoning by participants, and did not appear to impact questionnaire performance. The limited use of VIST principles is not surprising as Evans' (2012) study of tree graphics found that trees elicit explanations of relationships between species and common descent, but do not appear to support (and might impede) a grasp of natural selection. Furthermore, the use of mixed or hybrid reasoning about evolutionary change that incorporates elements of teleological explanations, such as needs-based reasoning that is influenced by ideas about function or habitat, with more scientifically accurate ones (e.g. mutation) is widespread and persistent even among undergraduates and experts (Rector, Nehm, & Pearl, 2013; Ware & Gelman, 2014).

Religious/Creationist Reasoning

Only one participant (Carol, aged 44, 005, linear tree) mentioned the role of religion as part of our discussion and provided a somewhat essentialist/creationist response towards the end of the interview. During most of the interview, she used the word ‘evolution’ and variations of it as did most participants, but when asked a follow-up question to her response about what the picture was trying to show about the two extant whales (*Balaenoptera musculus* and *Tursiops truncatus*)—“They came from the same genetic line”—she appeared to qualify the word ‘ancestor’, “Evolved from the same ancestor so to speak”. In response to a follow-up question to her statement that the graphic was showing where the animals come from, she said,

> ...from evolution. They’re *just here*. I mean, we, I can’t. I mean there – then it goes back to your basic values, if you believe in religion versus evolution mean, if you – ask a basic question, you know “Did God put us here or not”. But, you know, that’s a – different level. [emphasis mine].

However, she went on the say that the graphic was about science as would be expected in a science museum, and that it was important to understand the science view.

Carol was the only participant who disagreed (*mostly disagree*) with evolution as an explanation for the origins of birds and humans; she selected *mostly agree* for insects. Although she did not use more informed reasoning during the interview (i.e. use VIST principles), was the least supportive of evolution as an explanation for the origins of vertebrate groups, and indicated her knowledge of evolution as *some*, she performed well on the questionnaire earning the highest score of 11 out of 12. This might not be surprising since Carol self-reported a graduate degree in biology (the only participant to report a background in biology) and previous work has found that students with a stronger biology background perform better on some aspects of tree reading (Novick & Catley, 2013).

Variationist versus Transformationalist Change

Previous studies have compared variation-based and transformation-based ideas about evolutionary change, and found that the latter are pervasive (Shtulman, 2006; Shtulman & Schultz, 2008). Variationists view change as occurring in two steps involving mutation followed by selection acting on a population of individuals, which is consistent with the idea of common descent. In contrast, a transformationist views change as a process acting on a species' essence that is independent for each species (Shtulman & Calabi, 2012).

Four participants referred to variation and other VIST principles. Thomas (aged 45, 003, linear tree) described variation and differential reproduction when asked the following question: *At one time there was one species of animal, and now there are hippopotamuses, baleen whales and toothed whales. How do you explain that?*

> Uh. Well – the process of natural selection. Uh – an animal has lots of babies and if they thrive – they are rewarded by getting, they are able to live and then they make babies and if they don't thrive – they perish.

Peter's (aged 16, 002, linear tree) answer to this question included the idea of variation as well as differential survival,

> Um – the, the common ancestor was living in a certain time and something changed or a mutation occurred – and – and probably, probably both of those of those things happened – and the mutation made that select group or that individual more suited so that mutation, you know, developed and – kept, kept happening and so – ah, after a while, you know, they would split off and become two different species [rising pitch].

Mary (aged 41, 008, linear tree) described adaptation as needs-based change for an organism to survive, but within the context of selection and inheritance.

> …they needed to adapt to, um, survive in their environment. …through natural selection different – characteristics would evolve and um, be propagated, cause they would survive – and they would be, go on to, father – which propagate the species, so those characteristics would be dominant – um, and then they kept evolving depending on the climate they were in, depending on – the environment, how the Earth changed around them.

Judy (aged 42, 004, branched tree), referred to inheritance via reproduction "…through procreation this animal continues to pass through the generations [gesture with hand at Artiodactyl ancestor] and adaptions happen due to accidents or environment," as well as specific characters "…he got, you know, orange hair or something [gesture at *Pakicetus* and *Rodhocetus*] – and, and that was better."

While references to variation and selection were uncommon (Table 8) and included little detail, all participants accepted the idea of change between kinds and common ancestry, and in several cases talked about ancestors or common ancestors as populations (see later discussion). As noted earlier, prior work indicates that tree graphics do not elicit or support thinking about natural selection (Evans, et al., 2012); therefore, the limited presence of selection-related language is not unexpected. If we consider the framework of variationist versus transformationist ideas, the few participant responses in this study that refer to the process elements of change seem to be more consistent with a variationist rather than transformationalist change explanation; although, as will be discussed in the next section, more transformational-type explanations for evolutionary change are given for linear depictions of taxa.

Linear versus Branched Explanations

When asked about the whale tree graphic overall (i.e. *If you had to tell someone about this graphic, what would you tell them?*), participants often referred to the splitting of or a separation between the left and right branches at the root of the tree (hippo and whale lineages), frequently incorporating the Artiodactyl ancestor as part of the narrative. As Sarah (aged 47, 013, linear tree) described, "So there was one branch in the tree that split hippopotamus and the whales at 55 million, and then there's another branch at 35 million, that split the two whales." In general, explanations that incorporated the idea of a separation or division event or process referred to the three extant terminal taxa (hippos, baleen whales and toothed whales). Many such references also were made in the context of the two extant whales (baleen and toothed whales), which will be explored in more detail later.

<u>Interpretation of Branches and Nodes</u>

Participants interpreted branching as showing the connections or links between taxa, i.e. relationships. The specific points and pattern depicted by the branches often were highlighted through the use of gestures during explanations such as pointing at taxa and nodes, and tracing branches. Ann's (aged 11, 009, branched tree) response to what the picture was trying to show incorporated multiple gestures.

> So like this one [point left hand fingers at Artiodactyl ancestor] and then these [trace with left hand fingers along left branch to *Elomeryx* node; then trace down branch and up right side], this [point at *Pakicetus* node], and then that evolved from it [point at *Pakicetus*], and that [trace along right branch from *Pakicetus* to *Rodhocetus* node to *Rodhocetus*] evolved from those [point at *Pakicetus*, then trace up branch to *Dorudon*]…

A few participants specifically referred to the lines or branches, Melissa (aged 17, 007, branched tree) describing them as a connection, "It's showing us that because *Elomeryx* is only connected to the hippopotamus and the – Artiodactyl, whereas the others are all connected to, uh, the baleen whale and toothed whales." Judy (aged 42, 004, branched tree) referred to the graphic as a flow chart and used the term 'branch' when referring to particular parts.

Branching in the whale tree tended to elicit explanations that incorporated references to splitting, separation or divergence; however, different descriptions were given for what the nodes represented. Examples of specific references made about branching points include Judy (age 42, 002, branched tree) who incorporated nodes frequently through gestures during her explanations (see Figure **14**).

> …there's been a split [point at *Elomeryx*/Hippo node] and this guy [point at *Elomeryx*], who kinda looks like a – horse-dog sort of thing, uh, has that, that

> branch stopped evolving [trace from node to *Elomeryx*] and he has died out [point at *Elomeryx*] – and that this branch [trace from node to hippo], is this guy [point at *Hippopotamus amphibius*].

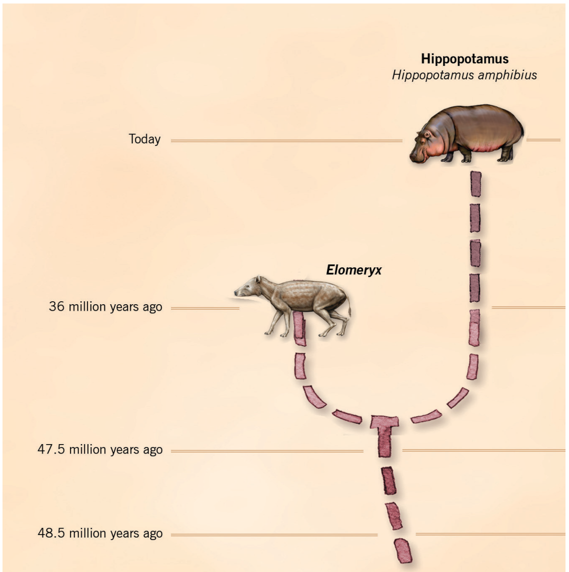

Figure 14 *Elomeryx* and hippo on branched whale graphic.

Judy also speculated that the nodes might represent a yet to be described taxon—in other words, a hypothetical ancestor.

> That this branch [trace from *Elomeryx/Hippopotamus amphibius* node to *Elomeryx*] from the common ancestor [point at node, then *Elomeryx*, then node again] is extinct. And that the hippopotamus [point at hippo, then node, then hippo again] is present day…And I'm – guessing that maybe there's an animal here [point at and draw circles around node] that maybe we haven't found any fossil record for so we don't have someone to name there.

Ellie's (aged 16, 015, branched tree) response also suggests that she thought nodes represented a taxon "…they came from the same kind of, subgroup [gesture with hand at *Elomeryx* node]."

Elliot (age 11, 016, branched tree), who said the branched *Elomeryx* and *Hippopotamus amphibius* were 'related', but also that the former represented 'an earlier stage of the latter', thought nodes were showing when and how long it took for change to occur—suggesting that she interprets them as change events (see Figure **15**).

> I mean like this took millions of years [trace with finger from root to *Elomeryx* node], this only took like a few million years [trace from root to *Pakicetus*, then to *Pakicetus* node, then to *Rodhocetus* node], and then that [trace from *Rodhocetus* node to *Dorudon* node]. Then it got a little bit bigger here [trace from *Dorudon* node to whale node].

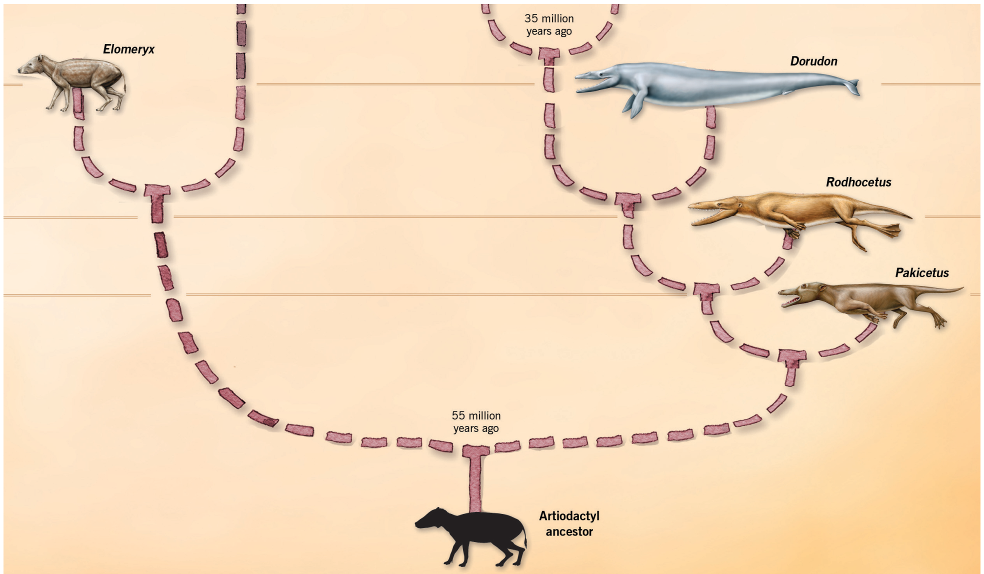

Figure 15 Extinct taxa on branched whale graphic.

Either interpretation (events or taxa) can be considered accurate since internal nodes can represent hypothetical (i.e. unnamed) ancestral taxa or speciation events depending on the tree form (Wiley, 2010). Technically speaking, in tree diagrams where nodes are ancestors, the branches represent relationship terms rather than lineages; whereas branches are ancestors (and other taxa) in trees where nodes are speciation events (Martin & Wiley, 2008). It is important to note that many tree graphics actually reflect hybridized versions of these forms (Wiley, 2010).

<u>Language Used</u>

The explanations and language used differed by depiction—linear or branched. Table 9 summaries the language used; Tables 10 and 11 provide excerpts from participant explanations for the taxa specific questions. 'Relatedness' was used to describe the general context of the graphic in terms of the whales and hippo lineages to each other (i.e. whales and hippos are related), the two terminal whale taxa (*Balaenoptera musculus* and *Tursiops truncatus*) that are branched in both versions of the tree, and for branched portrayals of *Elomeryx* and *Hippopotamus amphibius*. The terms 'evolved/came from' and 'common ancestor' were primarily used for explanations about branched taxa—i.e. baleen/toothed whales, hippo/whale lineages, and branched versions of *Elomeryx* and hippo—and often used alongside 'related' or 'relationships' to describe what the graphic was showing. 'Became', 'evolved into' and 'ancestor' tended to be used for linearly depicted taxa, i.e. *Elomeryx* and *Hippopotamus amphibius* and extinct taxa along the right branch (early relatives of whales) in the linear tree format.

Mary (aged 41, 008), viewing a linear tree format (Figure 16) used 'evolved from' and 'related' to describe the branched extant whales, and identified *Dorudon*—located at the baleen and toothed whale node in a linear tree format—as the ancestor. "Um, but there, they [whales] evolved from the same – ancestor from here [*Dorudon*]." Thomas (aged 45, 003), also using a linear version of the tree graphic, contrasted his interpretation of two sets of taxa (baleen and toothed whales, and *Elomeryx* and hippo) in the following way,

> Well – it seems like the hippopotamus is a dir, direct descendant of – the – *Elomeryx*. Whereas, these two [baleen and toothed whales] had a common ancestor [splitting movement with two fingers] in this [*Dorudon*] – it looks like this is a direct line [trace a line with finger from *Elomeryx* to hippo].

Similarly, Josh (aged 18, 019, linear tree) thought the graphic was showing that baleen and toothed whales are related, "…Similar to how we are related to monkeys – or you know primates, I guess.", but that "*Elomeryx* evolved into the hippopotamus, *Hippopotamus amphibius*."

Table 9 Relationship explanations provided during interview (by tree format, then age group); *whales branched in both tree formats.

			Baleen and Toothed*								*Elomeryx* and Hippo								General							
#	Age Group	Tree Format	Related	Evolved into	Became	Once was	Evolved from/ Came from	Ancestor/ Descendant	Common ancestor	Split/diverged/ separated	Related	Evolved into	Became	Once was	Evolved from/ Came from	Ancestor/ Descendant	Common ancestor	Split/diverged/ separated	Related	Evolved into	Became	Once was	Evolved from/ Came from	Ancestor/ Descendant	Common ancestor	Split/diverged/ separated
001	1	linear					✓						✓										✓	✓		
010	1	linear	✓[15]										✓							✓	✓					
017	1	linear								✓						✓[2]				✓				✓		✓
002	2	linear	✓											✓				✓	✓		✓			✓	✓	✓
012	2	linear	✓						✓						✓					✓				✓		✓
018	2	linear	✓									✓								✓			✓[11]			✓
003	3	linear	✓						✓	✓						✓[3]			✓					✓[6]	✓	✓
005	3	linear					✓	✓					✓						✓				✓			✓
008	3	linear	✓				✓	✓[7]								✓[2]							✓	✓		✓
013	3	linear							✓	✓						✓[3]								✓		✓
009	1	branched					✓[1]								✓[8]			✓	✓				✓[9]			✓
016	1	branched						✓			✓					✓[4]				✓[10]				✓		
020	1	branched					✓	✓[14]								✓[12]		✓		✓	✓					✓
007	2	branched	✓				✓				✓		✓										✓[5]			✓
015	2	branched					✓								✓								✓	✓		✓
019	2	branched	✓[15]				✓				✓[15]				✓			✓	✓	✓[13]	✓		✓			✓
004	3	branched	✓					✓		✓							✓	✓	✓	✓			✓	✓	✓	✓
006	3	branched	✓													✓[14]			✓					✓	✓	✓
011	3	branched	✓								✓									✓	✓					
014	3	branched	✓							✓					✓[8]			✓	✓					✓	✓	✓

Notes: [1] 'from same thing, but different'; [2] *Elomeryx* ancestor; [3] *Elomeryx* direct ancestor; [4] ancestor are versions; [5] 'from same creatures'; [6] right taxa descendants of earlier taxa; [7] *Dorudon* ancestor; [8] Hippo from *Elomeryx*, later from node; [9] from right taxa, changed to nodes; [10] 'Merged into'; [11] generalization; [12] *Elomeryx* ancestor of hippo, changed to node; [13] 'turns into; [14] Artiodactyl ancestor of both; [15] 'same family'.

Table 10 Participant explanations using a linear tree for taxa specific questions '*What do you think this picture is trying to show about…?*' (key terms in bold; *coded as related.). [1] Responses to other questions; [2] responses to follow up questions.

#	Age Group	*Balaenoptera musculus* and *Tursiops truncatus* (branched)	*Elomeryx* and *Hippopotamus amphibius* (linear)
001	1	That they both **evolved from** the same creature but they are two different things.	That the *Elomeryx* eventually **became** the *Hippopotamus*?
010	1	…they're similar but, uh, they look different but they're in like the **same family**.*	Um – that *Elomeryx* sort of **developed over time and became** sort of amphibious – uh, like a hippopotamus...
017	1	Um. How they were divided into a different species.	That the *Elomeryx* may be the **ancestor** of the *Hippopotamus.*
002	2	… not only are the two **related**, but that they are **related** to a hippopotamus.	…uh, the *Hippopotamus amphibius*, um, **once was** a type of *Elomeryx*, but then something happened...you know…a mutation that occurred and would split off …
012	2	Um. That they're different species but they're also **related** to each other, by a **common ancestor**.	Um. That the hippopotamus **evolved from** *Elomeryx*.
018	2	That they are **related**. Similar to how we are related to monkeys – or you know primates, I guess.	The *Elomeryx* **evolved into** the hippopotamus, *Hippopotamus amphibius*.
003	3	That they are **more closely related**…it looks they have become distinct species…That might be my **cousin***, not my cousin eight times removed …These two had a **common ancestor** in this [*Dorudon*].[1]	Well – it seems like the hippopotamus is a **dir, direct descendant** of – the – *Elomeryx*.
005	3	Same shared history…**Evolved from** the same, um, **ancestor** so to speak.	…um – over 36 million years it **became** a hippo – huh.
008	3	…they **evolved from** the same – ancestor from here [*Dorudon*]. …more **related** than say the hippopotamus and the baleen whale.[2]	… that's a lot of change. Between – I mean, for 36 million years ago – between that, those two. …*Elomeryx* is an **ancestor** of the hippopotamus.[2]
013	3	Um. That they – shared the **common ancestor** *Dorudon*… …there's another branch at 35 million, that **split** the two whales.[1]	That, um, hippopotamus is, um, well that – *Elomeryx* is a **direct ancestor** of hippopotamus. …evolution for the hipp, hippopotamus, um, going back to the *Elomeryx*…[1]

Table 11 Participant explanations using a branched tree for taxa specific questions '*What do you think this picture is trying to show about*…?' (key terms in bold; *coded as related.). [1] Responses to other questions; [2] responses to follow up questions.

#	Age Group	*Balaenoptera musculus* and *Tursiops truncatus* (branched)	*Elomeryx* and *Hippopotamus amphibius* (branched)
009	1	Maybe – they both **evolved from** the same thing…	…this guy [hippo] **evolved from** this guy [*Elomeryx*] …But, um, it, both of them **evolved from** this guy [Artiodactyl ancestor].
016	1	I think that it's trying to show you, about just kinda their **ancestors** and how they used to be, and just kind of to show you – just how they were made.	…there weren't very many – just **versions** of that animal before it came to the hippopotamus… look at all these whales and there's a bunch of them. And then you look at this and there's only a few **ancestors**. …you definitely tell that they're **related** cause, I mean, the ears are the same, the eyes are the same…but this [*Elomeryx*] seems like an early, definitely seems like an earlier stage.[2]
020	1	About their **ancestors** [Artiodactyl ancestor]. And, when this one branched…And…how they **evolved from** this [Artiodactyl ancestor, then extinct taxa on right branch] to how they are today.	Um. This is its **ancestor** [*Elomeryx* to node to hippo to *Elomeryx*]… Or, like this is the **ancestor** [*Elomeryx*/hippo node], and then this **branches off** this one [node to *Elomeryx*], this branches off this one [node to hippo].[2]
007	2	It's showing that, uh, they **evolved from** creatures that have had legs – or webbed feet at least at one point. …uh, baleen whales and the toothed whales are closely **related** today.[1]	It's showing that even *Elomeryx* is kinda **related** to the hippopotamus…more closely related…than, uh any of the other animals. …*Elomeryx* it went from, as it **became** hippopotamus[1]
015	2	Um. They both **came originally from** a subgroup that also created *Dorudon*.	Um, again they **came from** the same kind of, subgroup both dating back to the Artiodactyl.
019	2	It's trying to say that like – even though they look kind of the same but they are also very different, they both **come from** the same **family***.	…that they are far apart in like time wise, but again they **come from** the same **family*** even though the do look very different.

#	Age Group	*Balaenoptera musculus* and *Tursiops truncatus* (branched)	*Elomeryx* and *Hippopotamus amphibius* (branched)
004	3	Um, that they are **related** animals. That **split off** from a single **ancestor** 35 million years ago.	That they had a **common ancestor** I guess that would be like 45 million years ago or so.
006	3	I think how **closely related** they are. Maybe that all whales have these **common ancestors**.[2]	…we have quite a bit of contrast between *Elomeryx* and *Hippopotamus*, but I think looking at this **ancestor** [Artiodactyl ancestor] to *Elomeryx*…they almost look the same…it's showing how much of a change can happen… …hippopotamus is not **related** – uh, not as closely related to the whales…[1]
011	3	That they're **related**.	They're a little **more distantly related**.
014	3	They're **related**…somehow they kinda **split** and evolved differently but we can trace it back to the same animals.	Um. I'm not sure…but I can tell that – what it's trying to show is the hippopotamus somehow **evolved from** that, *Elomeryx* animal. …this animal evolved over time [Artiodactyl ancestor to *Elomeryx*/hippo node] and **split off** into two different adaptations [*Elomeryx*/hippo node to *Elomeryx*, then to hippo].[2]

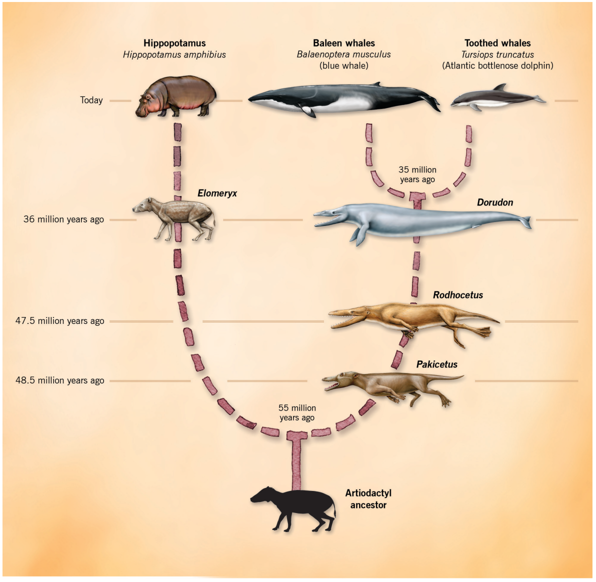

Figure 16 Linear whale tree graphic.

Additional examples that highlight the use of transformational or anagenic change language for linearly depicted taxa on the left branch include the following from Megan (aged 11, 001, linear tree), Carol (aged 44, 005, linear tree) and Andy (aged 12, 010, linear tree) who thought respectively that, "…the *Elomeryx* eventually became the *Hippopotamus*," and "…over 36 million years it [*Elomeryx*] became a hippo," and "Um – that *Elomeryx* sort of developed over time and became sort of amphibious…"

In contrast, branched depictions of *Elomeryx* and *Hippopotamus amphibius* (see Figure **17** for both branched and linear versions of this section) generally resulted in different terminology being used during explanations, participants used 'evolved/came from', 'related' and/or 'common ancestor', instead of 'became' or referring to *Elomeryx* as the ancestor of *Hippopotamus amphibius*. For example, Judy (aged 42, 004) said, "That they had a common ancestor.", Ellie (aged 16, 015) that "…they came from the same kind of subgroup.", and Samantha (aged 53, 011) "They're a little more distantly related." Branched tree users in the youngest age group (aged 11-13) used 'evolved from' and 'ancestors' when talking about both sets of taxa (baleen and toothed whales, *Elomeryx* and hippo); however, they talked about ancestors in a general sense or identified the Artiodactyl ancestor (Table 11).

Moreover, in the one case in which a participant used 'evolved from' to describe the relationship between *Elomeryx* and *Hippopotamus amphibius* in a linear tree (see Figure **17**), she said that "…the hippopotamus evolved from *Elomeryx*", and she talked differently about the branched taxa (whales) in that tree, "That they're different species but they're also related to each other, by a common ancestor." (Lucy, aged 14, 012).

In some cases participants offered different explanations when referring to taxa as part of a general rather than taxa specific question, or added to/modified their explanations during follow up questions. Melissa (aged 17, 007, branched tree) used 'became' in reference to *Elomeryx* and hippo in response to the question about what the tree shows generally, but when asked specifically about what the graphic was trying to show about *Elomeryx* and *Hippopotamus amphibius*, she said "It's showing that even *Elomeryx* is kinda related to the hippopotamus it's … more closely related to the hippopotamus than, uh, any of the other animals".

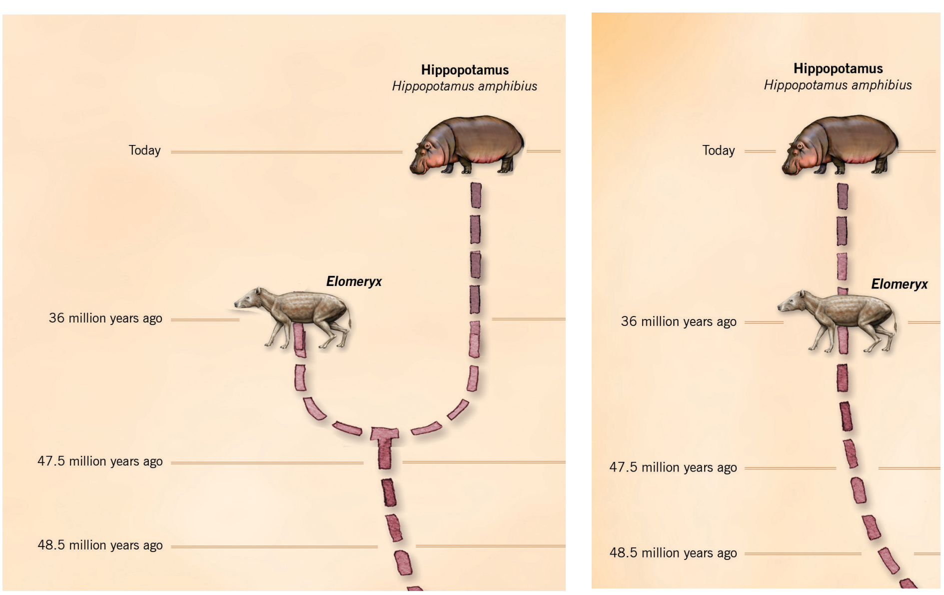

Figure 17 *Elomeryx* and hippo depictions (branched on left; linear on right).

Branched tree users typically used similar language to describe both baleen and toothed whales, and *Elomeryx* and hippo. For example, Samantha (aged 53, 011) and Camilla (aged 35, 006) described the two whale taxa as 'related' and *Elomeryx* and the hippo as 'more distantly related', Ellie (aged 16, 015) and Ann (aged 11, 009) referenced the historical context or origins of both sets of taxa ('evolved/came from'), Abby (aged 13, 020) and Elliot (aged 11, 016) thought that graphic was showing information about the 'ancestors'. Although, Judy (aged 42, 004) talked about 'common ancestors' for the whales, and *Elomeryx* and hippo, and also described the whales as 'related'.

'Relatedness' was used most often to describe the graphic overall and when describing the relationship between the two extant taxa on the right (*Balaenoptera musculus* and *Tursiops truncatus*, baleen and toothed whales), and to a lesser extent than for the extant and extinct taxa (*Elomeryx* and *Hippopotamus amphibius*) on the left (Table **9**). It is possible that some participants might be thinking differently about relationships, or at least the idea of being 'related' or 'closely related' within the context of the extinct/extant status of the taxa and/or whether the terminal end points vary on a graphic (e.g. branch length is calibrated by time). For example during the questionnaire, Josh (aged 18, 018, linear tree) asked if we wanted 'the one that is around today' for the answer to question 2, which asks which animal in the list of options is *Rodhocetus* is most closely related to—he was told that it did not have to be a living animal and that I wanted to know which he thought was the most closely related of all the choices. (Note: all participants answered this question incorrectly, see further discussion in the section about the questionnaire results).

An avenue that would warrant further investigation would be whether, and how, the particular context and combination of living or extinct taxa might influence the interpretation and explanation of relationships or relatedness. Some researchers have suggested that explicitly incorporating temporal information such as including extinct taxa with earlier end points might help support an understanding of trees and avoid misinterpretations such as tip reading, but that it also has the potential to reinforce ideas of progression in evolution or influence interpretation (Catley & Novick, 2008; Dodick, 2010; Donovan & Hornack, 2004).

In this study, the extinct taxa on the right branch of the tree rarely were talked about in detail—and were not asked about specifically as part of the standard interview questions—but differences in explanations for linear and branched representations were observed. Thomas (aged 45, 003) who used a linear tree talked about continuity among taxa "Well – if we look at the right side. I can see – it's easier for me to see the continuity. This [*Pakicetus*] to this [*Rodhocetus*] to this [*Dorudon*]…" While, Judy (aged 42, 004) who used a branched depiction described splitting along the right branch and considered what the nodes represented (see Figure 18).

> …this Artiodactyl, ancestor – he is, uh, split off at some point [*Pakicetus* node] and that this guy [*Pakicetus*] is extinct… but I wonder if maybe [pause] when, with this split [*Pakicetus* node] it's that this [*Pakicetus* node to *Rodhocetus* node] continues to evolve. So we can think of him [Artiodactyl ancestor] as, whatever he is [*Pakicetus* node], he evolves into this [*Pakicetus*] but then the other branch [*Pakicetus* node to *Rodhocetus* node] continues evolving, evolves into that [*Rodhocetus*], and then continues evolving [*Rodhocetus* node to *Dorudon* to baleen/toothed node].

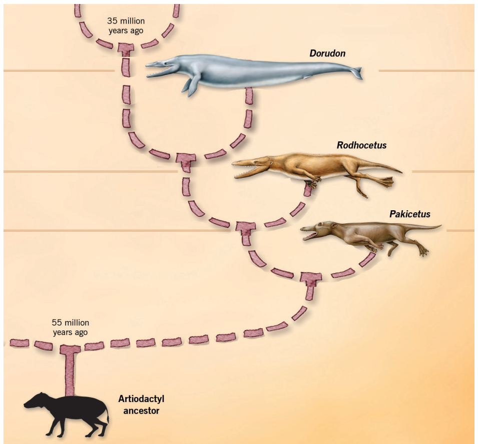

Figure 18 Artiodactyl ancestor and extinct taxa on right of branched whale graphic.

Tree Questionnaire – Overall Performance

Performance on the tree reading/interpretation section of the questionnaire was highly variable. No well-defined patterns were identified in terms of age group or tree format with respect to specific question types (ancestor, relationship, character); total and average scores, as well as responses to select items, however, did differ by tree format and by extension taxa depiction. In addition, a few themes of interest emerged from the pattern of incorrect answers.

Scores for the section that involved twelve multiple-choice ancestor, relationship and character questions ranged from two to eleven correct responses (Part A). Table 12 shows individual participant's responses to each question (organized by participant number), and Table **13** summarizes the overall questionnaire scores for Part A by age group and tree format. The ranges of scores for linear and branched trees are comparable—2 to 11 and 2 to 10 out of 12, respectively. Although the total scores for branched tree users generally were higher than those using linear trees, and the average number of correct answers also was higher (mean = 5.7 and 7.4; median = 5.5 and 8, respectively), this was not statistically significant.

The top third of scores (8 to 11 out of 12) fell within all three age groups (11-13, 14-18, adults); which is of interest given that the youngest participants are less likely than members of the older groups to have been exposed to trees as part of formal learning experiences—although they might have been exposed to tree graphics in informal learning contexts. Most older youth (aged 14-18) might recently have been or currently be learning about evolution in school, and the adults that might have learned about trees in school probably did so many years ago. The only adult participant that reported a background in biology (graduate degree) achieved the highest score with 11 out of 12. This individual also was the only participant who disagreed (*mostly disagree*) with evolution as an explanation for vertebrate origins on the questionnaire (i.e. birds

Table 12 Questionnaire responses Part A – ancestor (A), relationship (R) and character (C) questions (0 = incorrect/1 = correct).

				Part A											
#	Age	Tree Format	Total Correct	Q1 (A)	Q2 (R)	Q3 (C)	Q4 (R)	Q5 (A)	Q6 (C)	Q7 (R)	Q8 (A)	Q9 (C)	Q10 (R)	Q11 (A)	Q12 (C)
001	11	linear	5	0	0	1	0	1	1	0	0	1	0	1	0
002	16	linear	6	0	0	1	0	1	1	1	0	1	0	0	1
003	45	linear	2	0	0	0	0	1	0	1	0	0	0	0	0
004	42	branched	8	1	0	1	0	1	1	1	1	0	1	1	0
005	44	linear	11	1	0	1	1	1	1	1	1	1	1	1	1
006	35	branched	9	1	0	1	0	1	1	1	1	1	1	1	0
007	17	branched	9	1	0	0	0	1	1	1	1	1	1	1	1
008	41	linear	7	0	0	0	0	1	1	1	0	1	1	1	1
009	11	branched	8	1	0	1	0	1	1	1	0	0	1	1	1
010	12	linear	5	1	0	0	0	0	0	1	0	0	1	1	1
011	53	branched	10	1	0	1	0	1	1	1	1	1	1	1	1
012	14	linear	5	0	0	1	0	1	1	0	0	1	0	0	1
013	47	linear	6	0	0	0	0	1	1	1	1	1	0	1	0
014	37	branched	6	0	0	1	0	1	0	1	1	1	1	0	0
015	16	branched	9	1	0	0	0	1	1	1	1	1	1	1	1
016	11	branched	2	1	0	0	0	0	0	0	0	1	0	0	0
017	11	linear	3	0	0	0	0	1	1	1	0	0	0	0	0
018	18	linear	7	0	0	1	0	1	1	0	1	1	1	0	1
019	15	branched	7	0	0	1	0	0	1	1	0	1	1	1	1
020	13	branched	6	1	0	0	1	0	0	0	0	1	1	1	1

and humans), and gave a somewhat essentialist explanation for origins and creationist response during the interview.

Table 13 Questionnaire scores by age group and tree format for Part A.

Participant Age Group	Total Correct Responses (out of 12) Linear Tree Scores	Total Correct Responses (out of 12) Branched Tree Scores	Age Group Mean Linear tree	Age Group Mean Branched Tree
11-13	3, 5, 5	2, 6, 8	4.3 (SD = 1.15)	5.3 (SD = 3.06)
14-18	5, 6, 7	7, 9, 9	6.0 (SD = 1.00)	8.3 (SD = 1.15)
adult	2, 6, 7, 11	6, 8, 9, 10	6.5 (SD = 3.70)	8.3 (SD = 1.71)
	Mean = 5.7; SD = 2.45	Mean = 7.4; SD = 2.32		
	Median = 5.5	Median = 8.0		

The multiple-choice questions in Part A of the questionnaire involved reading and interpreting the tree graphic, and were focused on three ideas—(i) relatedness/relationships, (ii) common ancestry, and (iii) shared characters/features—with four questions in each category. Each category is discussed in turn below; correct responses are circled.

Relationship Questions (2, 4, 7, 10)

Relationships questions asked about which taxa are most closely related, and took two forms—identifying which taxon is most closely related to another (questions 2 and 10), and selecting the correct statement of relationships (questions 4 and 7). Two relationship questions in particular (questions 2 and 4, see below) appeared to be the most difficult, with none of the participants selecting the correct response for question 2, and only two correctly answering question 4.

Incorrect responses to relationship questions asked in the form of 'Which animal is x most closely related to?' (see questions 2 and 10 below) selected the ancestor/shared ancestor of the taxa referred to in the stem—i.e. *Pakicetus* and *Dorudon*, respectively—rather than the correct most recent/descendant taxa. In the case of question 2, all participants incorrectly selected *Pakicetus* (option (a)) as the taxon most closely related to *Rodhocetus*. While both linear and branched tree users incorrectly answered this question, branched tree users were more likely to answer question 10 correctly even though *Balaenoptera musculus* and *Tursiops truncatus* are depicted as branched in both versions of the tree graphic (see Table **14**). This difference was not statistically significant. In a future study it would be of interest to explore the reasoning involved in selecting responses by interviewing participants about their questionnaire choices.

Q2. Which animal is *Rodhocetus* most closely related to? (circle **one** answer)

a. *Pakicetus*
b. *Elomeryx*
c. *Balaenoptera musculus*
d. *Hippopotamus amphibius*

Q10. Which animal is *Balaenoptera musculus* most closely related to? (circle **one** answer)

a. *Hippopotamus amphibius*
b. *Tursiops truncatus*
c. *Elomeryx*
d. *Dorudon*

Table 14 Responses to question 10 (relationship question) by tree format.

Question 10 Responses			
	Linear Tree	Branched Tree	Total
Correct	4	9	13
Incorrect	6	1	7
Total	10	10	20

When asked about a given taxon's relationship to two others, many participants opted for them to be equally related to two other taxa (e.g. see question 4); others selected the nearest taxon in terms of proximity as being more closely related (or in one case as being only related), which could be and likely was in some cases interpreted as an 'ancestor' (i.e. *Rodhocetus*).

Q4. Which of the following is an accurate statement of relationships? (circle **<u>one</u>** answer).

a. *Dorudon* is related to *Rodhocetus*, but is not related to *Tursiops truncatus*
b. *Dorudon* is more closely related to *Tursiops truncatus* than to *Rodhocetus*
c. *Dorudon* is more closely related to *Rodhocetus* than to *Tursiops truncatus*
d. *Dorudon* is equally related to *Tursiops truncatus* and *Rodhocetus*

The relationship question that was answered correctly most often was question 7 (see below), regardless of tree format. It is interesting to note that this was the only relationship question that incorporated taxa on both sides of the graphic, with the correct option selecting the only two taxa on the same branch as being more closely related to each other (*Elomeryx* and *Hippopotamus amphibius*). Incorrect responses to this question selected option (b), which states that *Elomeryx* is related to *Hippopotamus amphibius,* but not to *Pakicetus*—located on the right branch of the tree.

Q7. Which of the following is an accurate statement of relationships? (circle **<u>one</u>** answer)

a. *Elomeryx* is equally related to *Pakicetus* and *Hippopotamus amphibius*
b. *Elomeryx* is related to *Hippopotamus amphibius,* but is not related to *Pakicetus*
c. *Elomeryx* is more closely related to *Pakicetus* than to *Hippopotamus amphibius*
d. *Elomeryx* is more closely related to *Hippopotamus amphibius* than to *Pakicetus*

<u>Ancestor Questions (1, 5, 8, 11)</u>

Ancestor questions focus on identifying which two taxa shared a common ancestor most recently or when a shared common ancestor of two taxa would have lived. Branched trees users gave correct responses more often to one particular ancestor question—question 1, a 'which' question that asked them to identify the two taxa with the most recent common ancestor (see below). This was the only question where the difference in performance between trees was statistically significant at $p<0.01$ (one-way ANOVA $F=10.125$; $p=0.0051$).

Q1. Which two animals have an ancestor in common most recently? (circle **one** answer)

a. *Rodhocetus* and *Elomeryx*
b. *Rodhocetus* and *Pakicetus*
c. *Balaenoptera musculus* and *Pakicetus*
d. *Hippopotamus amphibius* and *Elomeryx*

Only two linear tree users, one of whom holds a graduate degree in biology, correctly identified *Hippopotamus amphibius* and *Elomeryx* as having shared a common ancestor most recently from the options provided (Table 15). Two branched tree users incorrectly answered this question; one was an adult participant that struggled with their interpretation of the branched depiction of these taxa (participant 014, see discussion in *Meaning and Significance of Branching* in Chapter VI).

Table 15 Responses to question 1 (ancestor question) by tree format.

Question 1 Responses			
	Linear Tree	Branched Tree	Total
Correct	2	8	10
Incorrect	8	2	10
Total	10	10	20

Similar to the pattern of incorrect responses seen for relationship questions, most incorrect answers to this ancestor question (8 of 10) selected the two taxa that were the closest in terms of vertical proximity and had the shortest time period between them (option (b), *Rodhocetus* and *Pakicetus*). For question 11 (see below), the other ‘which’ ancestor question, all incorrect responses—in both linear and branched tree users—selected the graphically and temporally nearest taxa, *Rodhocetus* and *Pakicetus* (option d). Although branched tree users were more likely to answer this question correctly, half of participants using a linear tree provided correct responses (Table **16**).

Q11. Which two animals have an ancestor in common most recently? (circle **one** answer)

a. *Balaenoptera musculus* and *Rodhocetus*
b. *Dorudon* and *Tursiops truncatus*
c. *Elomeryx* and *Pakicetus*
d. *Rodhocetus* and *Pakicetus*

Table 16 Responses to question 11 (relationship question) by tree format.

Question 11 Responses			
	Linear Tree	Branched Tree	Total
Correct	5	8	13
Incorrect	5	2	7
Total	10	10	20

Question 5 (see below) seemed to be the easiest ancestor question for participants to answer, with only four incorrect responses. Question 5 is a 'when' ancestor question, and selecting the correct answer involved reading time at a defined branching point that was labeled 'Artiodactyl ancestor' on both versions of the tree graphic. Incorrect responses to this question selected (b) or (c); the two options that include the time range between the two named taxa in the stem.

Q5. When did *Elomeryx* and *Rodhocetus* have an ancestor in common most recently? (circle **one** answer)

a. About 55 million years ago
b. Between 48.5 and 47.5 million years ago
c. Between 47.5 and 36 million years ago
d. Less than 35 million years ago

The other 'when' ancestor question, question 8 (see below), required identifying the time range between *Rodhocetus* and *Pakicetus* (option (c)). Unlike the other 'when' question, it does not involved reading time in association with a labeled 'ancestor'. Branched tree users select the correct answer more often—6 correct responses compared to 3 for linear tree users. All incorrect responses selected an option that included the most recent time period marked on the graphic, 36 million years ago (options (a) and (b)).

Q8. How old would the ancestor that *Balaenoptera musculus* and *Rodhocetus* have in common most recently be? (circle **one** answer)

a. Between 36 and 35 million years ago
b. Between 47.5 and 36 million years ago
c. Between 47.5 and 55 million years ago
d. About 55 million years ago

Character Questions (3, 6, 9, 12)

Character questions involved identifying all taxa that would share a particular feature or trait (i.e. a synapomorphy or shared derived character). There was no distinct pattern for character questions that differed by tree format. If we consider these questions in terms of what direction the graphic needs to be read and interpreted from the named taxon in the stem, however, questions that require only reading up the tree (see questions 6 and 9 below) were most often answered correctly (15 out of 20).

Question 6 required selecting all later/descendant taxa; four of the five incorrect responses correctly identified *Dorudon* as having the trait, but excluded the extant *Tursiops truncatus* (the other incorrect response selected all taxa). Character question 9 also required selecting the later/descendant taxa from the named taxon in the stem. Four of the five incorrect responses to this question selected earlier taxa such as *Pakicetus* and/or the Artiodactyl ancestor, and did not identify the extant baleen whale *Balaenoptera musculus* as having the trait (the other incorrect response selected both extant taxa, *Balaenoptera musculus* and *Hippopotamus amphibius*).

Q6. If the ancestor of *Rodhocetus* evolved a specific trait, which animals would you expect to have the same trait? (circle **all** correct answers)

a. *Elomeryx*
b. *Dorudon*
c. *Tursiops truncatus*
d. Artiodactyl ancestor

Q9. If the ancestor of *Dorudon* evolved a specific trait, which animals would you expect to have the same trait? (circle **all** correct answers)

a. *Pakicetus*
b. Artiodactyl ancestor
c. *Balaenoptera musculus*
d. *Hippopotamus amphibius*

Questions 3 and 12 (see below) required reading both up and down the tree graphic from the named taxa in the stem to identify the other taxa listed that would share a particular trait. In other words, the correct response involved selecting both shared ancestors as well as descendants. For question 3, most incorrect responses only selected Artiodactyl ancestor or only chose the taxon on the left branch (*Elomeryx*). For question 12, the pattern was similar to what was observed for character question 6—incorrect responses identified earlier taxon/shared ancestor as sharing the trait, but not later taxa/descendants. All respondents correctly identified *Dorudon*—an ancestor/common ancestor of *Balaenoptera musculus* (depending on the individual's interpretation of the depiction) as having the shared character—but did not select the other extant taxa listed or the sister group to baleen whales, *Tursiops truncatus* or toothed whales.

Q3. If a fossil whale from 54 million years ago, *Hippopotamus amphibius* and *Tursiops truncatus* were found to have similar wrist bones, what other animals would you expect to have the same trait? (circle **all** correct answers).

a. *Pakicetus*
b. *Elomeryx*
c. *Rodhocetus*
d. Artiodactyl ancestor

Q12. If a fossil whale from 40 million years ago, *Balaenoptera musculus* and *Rodhocetus* were found to have similar skull bones, what other animals would you expect to have the same trait? (circle **all** correct answers).

a. *Dorudon*
b. *Elomeryx*
c. *Pakicetus*
d. *Tursiops truncatus*

Ideas about Evolution and Museum Visitation

Table **17** summarizes the responses for Part C of the questionnaire, which asks participants for their ideas about evolution as an explanation of origins for three groups, its importance as a topic to know about, as well as their knowledge of the topic. Fifteen out of twenty participants *agreed* with evolutionary as an explanation for the origins of insects, birds and humans. Two participants agreed to a lesser extent with an evolutionary explanation for the origin of insects than birds and humans (007, 017). One individual disagreed (*mostly disagree*) with an evolutionary explanation for the origins of both vertebrate groups (birds and humans), but agreed (*mostly agree*) for insects. No participants agreed to a lesser extent for evolution as an explanation for human origins compared to birds and insects; i.e. they agreed to an equal or greater degree for evolution as an explanation for human origins as they did for one or both of the other groups.

All participants thought it was *pretty* or *very important* for scientists to know about evolution, while feeling that it was equally or slightly less important for them to know about evolution; one person felt that was only *a little important* to know about evolution. Over half of participants (11 out of 20) reported their own knowledge of evolution as *some*, one as *a little bit*, two as *a lot*, and three as *quite a* bit. Two participants indicated a range between two options; *quite a bit* to *a lot* and *some* to *quite a bit*. Part C also asked about participants' number of museum visits each year, which ranged from two to more than 30 annual trips to museums.

Table 17 Questionnaire response for Part C.

#	Age	Tree Format	Total Correct	Part C Q1: insect origins	Q2: human origins	Q3: bird origins	Q4: Scientists to know	Q5: You to know	Q6: knowledge
001	11	linear	5	agree	agree	agree	pretty important	pretty important	some
002	16	linear	6	agree	agree	agree	very important	very important	some
003	45	linear	2	agree	agree	agree	very important	pretty important	quite a bit
004	42	branched	8	agree	agree	agree	very important	pretty important	some
005	44	linear	11	mostly agree	mostly disagree	mostly disagree	very important	a little important	some
006	35	branched	9	agree	agree	agree	very important	pretty important	some
007	17	branched	9	mostly agree	agree	agree	very important	pretty important	a lot
008	41	linear	7	agree	agree	agree	very important	very important	quite a bit
009	11	branched	8	mostly agree	mostly agree	mostly agree	pretty important	pretty important	a little bit
010	12	linear	5	mostly agree	agree	mostly agree	very important	pretty important	quite a bit
011	53	branched	10	agree	agree	agree	very important	very important	some
012	14	linear	5	agree	agree	agree	pretty important	pretty important	some
013	47	linear	6	agree	agree	agree	very important	very important	some
014	37	branched	6	agree	agree	agree	very important	very important	some
015	16	branched	9	agree	agree	agree	very important	very important	some
016	11	branched	2	agree	agree	agree	very important	pretty important	a lot
017	11	linear	3	mostly disagree	agree	mostly agree	pretty important	very important	some
018	18	linear	7	agree	agree	agree	very important	very important	quite a bit
019	15	branched	7	agree	agree	agree	very important	very important	quite a bit – a lot
020	13	branched	6	agree	agree	agree	very important	very important	some – quite a bit

Self-reported knowledge about or acceptance of evolution as an explanation for the origins of insects, birds and human did not appear to be linked to questionnaire performance. Neither was the number of annual museum visits; although it should be noted that the questionnaire did not distinguish between science-focused and other museums or whether these visits represented separate institutions or repeat visits to one museum.

Summary of Findings

This qualitative study explored how linear and branched depictions of taxa in tree graphics influence visitors' reading and interpretation of evolutionary relationships. Overall, tree diagrams appear to support the idea of common descent, and that change between kinds can occur. In addition, mixed reasoning about evolutionary change—i.e. includes intuitive (e.g. need-based) and scientifically accurate (e.g. selection) ideas—is common across a wide age range.

Findings from this research indicate that branched depictions of taxa can influence narratives about the nature of evolutionary relationships between taxa and change explanations, as well as some aspects of tree reading and interpretation. Explanations by branched trees users were more likely to include references to splitting, separation or divergence, and describe relationships among taxa as having 'evolved from' something else and/or as 'related'. Nodes or branching points were correctly interpreted as evolutionary events or shared/common ancestors. Branched tree users were also better able to correctly identify taxa that would have shared a common ancestor most recently. Linear tree users tended to describe relationships in terms of anagenesis, a direct linear transformation from one species into another (i.e. described one as being the direct ancestor of another or that one 'became' the other). In other words, linear depictions appear to support more intuitive and scientifically incorrect interpretations, whereas branched depictions facilitate more scientifically accurate explanations.

CHAPTER VI: INTERPRETATIONS

This exploratory study sought to investigate the influence of tree graphic design—specifically linear versus branching depictions of taxa—on interpretation and understanding by visitors of different ages using a multiple-case study strategy. The findings indicate that linear and branched depictions elicit qualitatively different narratives and explanations about the relationship between the taxa—with branched tree graphics resulting in more scientifically appropriate descriptions than linear tree graphics across all age groups.

The impact of tree graphic design on tree reading and interpretation, as indicated by questionnaire responses, was variable across ages and tree formats, although participants presented with branched tree graphics had higher scores overall, and performed better on selected ancestor questions than participants presented with linear tree graphics. In addition, the results of the questionnaire lend further support to, and extend, previous work on tree reading challenges (e.g. the difficulty of relationship questions), as well as highlighting several patterns that are of interest for future studies.

Meaning and Significance of Branching

Participant explanations and the language used to describe relationships differed by tree graphic format. Branched depictions of taxa were more likely than linear tree depictions to elicit references to taxa or changes as resulting from a splitting, divergence or separation of groups (i.e. cladogenesis); with nodes viewed as hypothetical ancestors or separation events. Participants described taxa as being ‘related’ or having ‘evolved from’ the same or a shared ancestor in branched representations, in contrast with linear depictions that resulted in the use of more transformational (i.e. anagenesis) language such as ‘became’.

Contrasting the language used to describe what the tree was trying to show about *Elomeryx* and *Hippopotamus amphibius* between the two tree formats is particularly informative, and is summarized in Table **18** along with the terminology used for the whales. Participants used the term 'ancestor' to describe *Elomeryx* as the ancestor of the hippo in linear trees; whereas in branched trees, 'ancestor' was typically used to refer to the *Elomeryx*/hippo node as the ancestor of both *Elomeryx* and *Hippopotamus amphibius*—although in one case, ancestors were seen as versions of extant taxa. The only participant who made a reference to divergence when using a linear tree described the hippo as a type of *Elomeryx* that split (participant 002).

Table 18 Terminology used in response to "What do you think this graphic is trying to show you about…?" in linear versus branched trees. **Dorudon* at baleen/toothed whale node in linear tree.

	Linear Depiction	Branched Depiction		
	Elomeryx and *Hippopotamus*	*Elomeryx* and *Hippopotamus*	**Balaenoptera* and *Tursiops*	*Balaenoptera* and *Tursiops*
Related	0	**3**	**5**	**5**
Evolved into	1	0	0	0
Became	**3**	1	0	0
Once was	1	0	0	0
Evolved/Came from	1	**4**	**3**	**4**
Ancestor/Descendant	3	3	1	2
Common ancestor	0	1	3	0
Split/Diverged/Separated	1	**5**	**3**	**2**

A few participants struggled with their thinking about and interpretation of what the branching meant. This can be seen in participants' responses to the question "What do you think this graphic is trying to show you about *Elomeryx* and *Hippopotamus amphibius*?" Their explanations are of particular interest because they provide some valuable insight into their reasoning about branched depictions.

Ann (aged 11, 009, branched tree) talked about hippos and whales being 'related' a long time ago, and said that things 'evolved from' other things—generally gesturing towards named terminal taxa—but did not refer to them as ancestors. At other times she followed the branches connecting particular taxa and referenced the nodes during her explanations).

> But this one is starting to evolve [trace *Elomeryx* node to hippo], and then it splits off into these [trace whale node to baleen whale and then toothed whale], and then they all, these three evolve [point at hippo, baleen whale, toothed whale] – like at the same time, ish.

In reference to the taxa on the right side of the tree (see Figure **19**),

> …that [point at *Pakicetus*] evolves from that [point at *Pakicetus*; then trace along branch to *Rodhocetus* node], and then that [*Pakicetus*] evolves from that [*Rodhocetus*]. Yeah, so this goes up [along bottom branch up right side to *Pakicetus* node], so this one [*Rodhocetus*] evolves from this one [rising tone] [*Pakicetus*] and then this guy [*Dorudon*].

She described *Hippopotamus amphibius* as having 'evolved from' *Elomeryx*, then later from the node, and appeared to view the branching points as important. Ann considered all terminal taxa as distinct entities, and potentially that nodes were also separate entities.

> …so, like these evolve slowly [one hand traced from *Elomeryx* node to *Elomeryx*, the other from the node to hippo], but this one takes longer [hippo]. So once this is fully evolved [*Elomeryx*], then this [from *Elomeryx* to node, then from node to hippo] gets off of that [hippo].

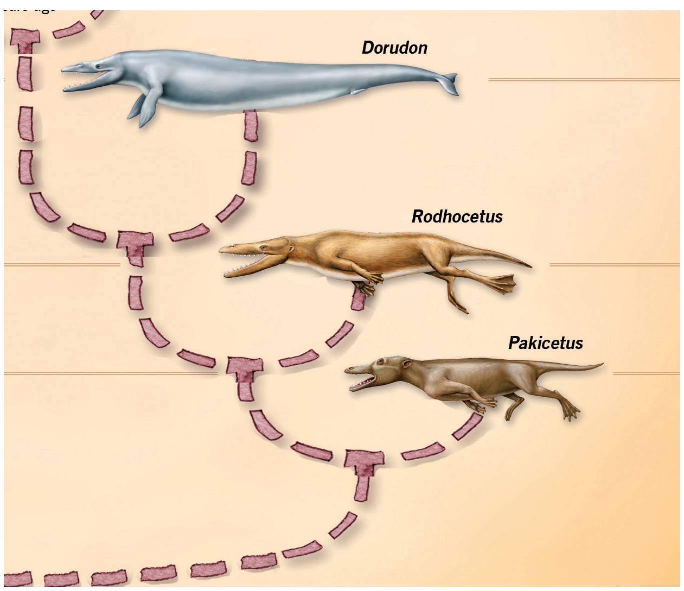

Figure 19 Extinct taxa on right of branched whale graphic.

Alexa (aged 37, 014, branched tree) expressed some confusion during her interview about why the connection between *Elomeryx* and *Hippopotamus amphibius* was not shown as a straight line. She thought that perhaps the branching might mean something, but seemed confident in the idea that it was showing that the hippo 'evolved from' *Elomeryx*. Although she used 'evolved from' rather than 'became' in her explanation, which is consistent with other branched tree users, her reflection on the significance of the branched depiction is of interest—as illustrated in the extended excerpt from the interview transcript below; I: interviewer, P: participant (see Figure 14 replicated below for reference).

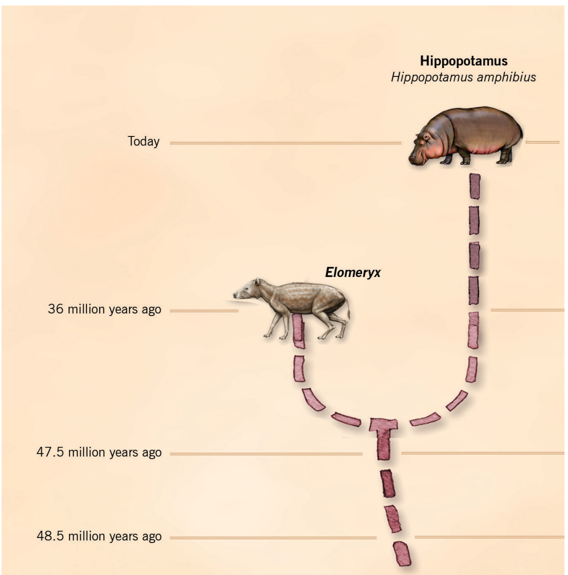

Figure 14 *Elomeryx* and hippo on branched whale graphic.

I: What do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius*?

P: Um. I'm not sure. [pause] I mean, if I really sit and analyze like, why it's not just like straight [open hand held flat and directed upwards at ~45 degree angle and moved in a straight line from *Elomeryx* to hippo area of graphic] – but, I see it's kinda curved [trace with finger from *Elomeryx* area to *Elomeryx*/hippo node and up right (hippo) branch], I don't know if that means anything [laughs]. Um, but I can tell that – what it's trying to show is the hippopotamus somehow evolved from that, *Elomeryx* animal [rising tone].

I: OK. So you think that hippopotamus evolved from *Elomeryx*?

P: Not sure. Um. [pause] I guess yeah, if I just looking at it that's what I would think, that they're somehow connected like that yeah.

I: You commented on this not being a straight line though [trace with finger from *Elomeryx* to *Elomeryx*/hippo node to just past node].

P: …so, this is 47.5 million years [point at 47.5 million years ago text, then move across to branch to just below *Elomeryx* node], and then is thirty [trace from *Elomeryx*/hippo node to *Elomeryx*], I don't know it just kinda curves back down and then goes up [trace branch with finger from *Elomeryx* to Elomeryx/hippo node and up right branch to hippo] instead of [open hand held flat and directed upwards at ~45 degree angle and moved in a straight line from *Elomeryx* area to hippo area of graphic].

I: So, what do think that might mean, or might be trying to show you?

P: Um [rising tone]. So, this animal evolved over time [point at Artiodactyl ancestor; then trace from Artiodactyl node to *Elomeryx* node] and split off into two different adaptations [rising tone] [trace from *Elomeryx* node to *Elomeryx*, then from node to hippo].

Also of interest is that Alexa was one of only two participants using a branched tree graphic who incorrectly answered question 1 on the questionnaire (Part A)—that asks which of four pairs of taxa listed have an ancestor in common most recently; the correct response is *Hippopotamus amphibius* and *Elomeryx*. Although the branched depiction supported a more scientific (i.e. cladogenic) interpretation of evolutionary relationships as seen in her follow up explanations, she reverted to using a more intuitive linear or anagenic interpretation in her questionnaire responses, e.g. reflecting her initial expectation of a straight line connecting taxa.

The idea that a particular graphic depiction might conflict with or be incongruent with an individual's existing or recently learned ideas about evolution was also seen in Peter's (aged 16, 002, linear tree) response to what a linear tree was trying to show about *Elomeryx* and *Hippopotamus amphibius*. His initial explanation for the linearly arranged taxa on the left (*Elomeryx* and *Hippopotamus amphibius*, see Figure **20**) suggests an initial interpretation of change as transformational or developmental—that the hippo once was a type of *Elomeryx*—and is similar to descriptions by other linear tree users. However, this explanation was followed by a description that suggests divergence.

> Um – I think it would be showing that – uh, the *Hippopotamus amphibius*, um, once was a type of *Elomeryx*, but then [snaps fingers] something happening. And I guess with my understanding of evolution, you know, there would be – a mutation that occurred and would split off and maybe the *Elomeryx* was wasn't so suited for survival anymore and went, went, uh, onto become extinct, but the *Hippopotamus* was so it is still alive.

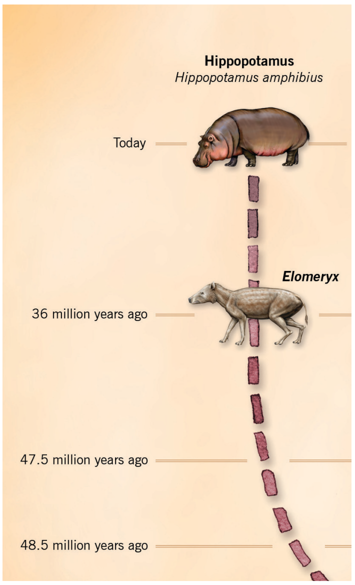

Figure 20 *Elomeryx* and hippo on linear tree graphic.

Similarly, Josh (aged 18, 019, linear tree) provided conflicting explanations—he described the two extant whale taxa as related, "Similar to how we are related to monkeys – or you know primates, I guess," and said that "*Elomeryx* evolved into the hippopotamus, *Hippopotamus amphibius*."—which is consistent with other linear tree users. Yet later he described how the tree could be used to teach about evolution, specifically noting that the idea that an extant taxon directly evolved from another group is incorrect, and referencing the bottom branching point/node on the linear tree when doing so (note: one of only two branching points on the linear tree format).

> …I would need more to explain it – but like how you know some of this animal went in this direction and some of this animal went in this direction [point with both hands at Artiodactyl ancestor, then trace up left branch with left hand to *Elomeryx*, and with right hand up right branch to *Dorudon*] and I could compare that to how everyone thinks that we directly evolved from monkeys and that's not true [gesture with both hands generally towards me] – you know, that we're just

> on the same branch of the same tree [split movement with both hands from bottom of graphic up left and right branches] – I guess.

As with most linear tree users, Peter and Josh incorrectly answered question 1—i.e. did not identify *Elomeryx* and *Hippopotamus amphibius* as the two most closely related taxa among the options provided (they both selected *Rodhocetus* and *Pakicetus*). This suggests that their initial (and graphic focused) explanations during the interview and questionnaire responses reflect more intuitive reasoning—and that a linear depiction reinforces this naïve interpretation.

Melissa's (aged 17, 007, branched tree) explanations provide an example of how a branched graphic representation of taxa might help to mediate an intuitive anagenic interpretation of evolutionary relationships and support a more scientifically accurate one. Her initial description when asked what she saw in the graphic includes transformative language, e.g.

> You can see animals that have gone from having – legs to seemingly to having fins. As well as animals going from having longer legs to shorter legs…*Elomeryx* it went from, as it became hippopotamus and that given a shorter tail.

For *Balaenoptera musculus* and *Tursiops truncatus*, she described them as evolving from other creatures based on the branches "…they evolved from creatures that have had legs – or webbed feet at least at one point…because the lines are connecting." Later, Melissa said the graphic showed that *Elomeryx* and *Hippopotamus amphibius* are related, "…kinda related to the hippopotamus it's not as closely related as [pause] well, or it's closely, more closely related to the hippopotamus than, uh, any of the other animals." When asked how it showed that, she referred to the branching "…because *Elomeryx* is only connected to the hippopotamus and the – Artiodactyl, whereas the others are all connected to, uh, the baleen whale and toothed whales."

Nodes are an important graphic feature of branched depictions of taxa. Judy (aged 42, 004, branched tree) often referenced nodes and associated branches as part of her explanations—and reflected on and revised her own thinking about the meaning of nodes during the interview.

Thinking aloud, she asked herself "Would that mean that *Pakicetus* is here [point at *Pakicetus* node] – but then his ancestors continued evolving [point at *Rodhocetus* node] – and then… ahhh [frustrated]," and then provided the following more detailed explanation (see Figure **21**).

> Well, I think the Artiodactyl [point at Artiodactyl ancestor] as he evolves [trace along bottom branch to *Pakicetus* node] – he evolves into *Pakicetus* [point at *Pakicetus*]. And then [point at *Pakicetus* node] that – whatever ancestors [point at *Pakicetus* and then *Pakicetus* node] adapted to the changing times [point at *Rodhocetus* node, then *Pakicetus* node, then back to *Rodhocetus* node], and the predators and things – left *Pakicetus* behind [trace from *Pakicetus* along branch to *Rodhocetus* node]. So I don't think he looked like this [point at Artiodactyl ancestor] – you know – 52 million years ago [point at *Pakicetus* node]. I think that as he was evolving [trace along branch from Artiodactyl ancestor to *Pakicetus*] this guy got left behind [point at *Pakicetus*] and he continued to evolve [point at *Pakicetus* node, *Rodhocetus* node, *Rodhocetus*, then *Dorudon* node]. So he looked a lot like *Pakicetus* here [point at branch section between *Pakicetus* and *Rodhocetus* nodes].

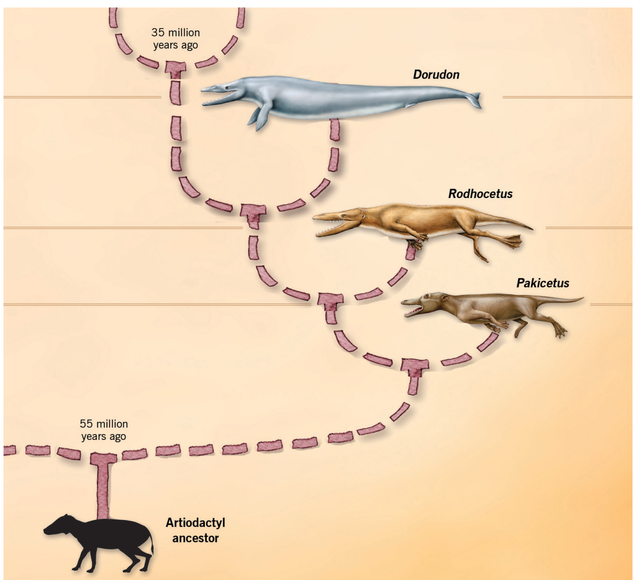

Figure 21 Artiodactyl ancestor and extinct taxa on right of branched whale graphic.

Branched trees users who talked or were asked about nodes viewed them as hypothetical ancestors or separation events, which raises the question of what role the nodes might play in the interpretation of a branched depiction of taxa. Abby (aged 13, 020, branched tree) explained the relationship between *Elomeryx* and *Hippopotamus amphibius* by referring to ancestors, but her description and accompanying gestures changed and incorporated *Elomeryx*, the *Elomeryx*/hippo node as well as the Artiodactyl ancestor as shown in the extended (but edited) interview excerpt below. Although, she was unsure about what nodes represent, her explanation changed from *Elomeryx* as the ancestor of *Hippopotamus amphibius*, i.e. anagenic, to one in which the node is the shared ancestor or signified a divergence event.

P: Um. This is its ancestor [trace from *Elomeryx* along branch to *Elomeryx*/hippo node and to hippo, then to *Elomeryx*] [pause] [gesture between Artiodactyl ancestor, then Elomeryx, then back].

I: You think. Something is one's ancestor?

P: Mm-hmm.

I: Which do you think is the ancestor?

P: This [point to *Elomeryx*, then Artiodactyl ancestor, then *Elomeryx*, then hippo] and here.

I: These ones? You think these both [point at *Elomeryx*, then Artiodactyl ancestor, then *Elomeryx*, then Artiodactyl ancestor] are the ancestors of that one [point at hippo]?

P: Well [point at *Elomeryx*, then Artiodactyl ancestor] is the ancestor of this one [*Elomeryx*]? And then it goes to that [trace from *Elomeryx* along branch to *Elomeryx*/hippo node, then point at hippo].

I: OK. So you think that's [point at Artiodactyl ancestor] the ancestor of that one [point at *Elomeryx*]?

P: Or, like this is the ancestor [point at *Elomeryx*/hippo node], and then this branches off this one [trace from node to *Elomeryx*] this branches off this one [trace from *Elomeryx*/hippo node to hippo].

I: So, you think this [Artiodactyl ancestor] is the ancestor of this [point at and circular movement around *Elomeryx*/hippo node]?

P: Mm-hmm.

I: What do you think this [point at node] is?

P: Uh. [pause] I don't really know.

I: Do you think – what do you think these points [point at *Elomeryx*/hippo node, then baleen and toothed whales node, then *Dorudon* node, then *Rodhocetus* node] – do you think these are trying to show anything – or not?

P: Um. [long pause] They have like a time and a new, branch that starts [trails off].

Based on prior work, it is not clear what role nodes labeled as 'ancestor' might play in tree reading and interpretation. Donovan and Wilcox (2004) suggest that labeling the root or other internal node as 'common ancestor' can help support the interpretation of nodes, while Catley and Novick (2008) have argued that including an unknown ancestor is disingenuous. The findings from this study suggest that a branched tree format—which results in nodes—supports a shift in interpretation from transformational or anagenic change towards a more scientifically appropriate cladogenic one. However, general explanations given for the tree overall (i.e. not about specific taxa) with 'Artiodactyl ancestor' labeled at the bottom branching point reflected a wide range of language and descriptions including 'related', 'splitting', 'common ancestor' as well as 'evolved into', 'became', and 'ancestor/descendants' (see Table **9**).

For example, Abby (aged 13, 020, branched tree) said that the graphic was trying to show something about the ancestors of *Balaenoptera musculus* and *Tursiops truncatus*: when the Artiodactyl ancestor branched and "….how they evolved from this [point right hand finger at Artiodactyl ancestor, then extinct taxa on right] to how they are today [point at *Balaenoptera musculus*]." Josh (aged 18, 018, linear tree) thought the Artiodactyl ancestor was blacked out because it represented the 'starting point', which then 'evolved into' the taxa on the right branch.

Nodes are both a graphic consequence of and important interpretive element in branched tree diagrams. Participants' explanations of these branching points in this study suggest that their interpretation could play a role in supporting an accurate understanding of evolutionary relationships and/or change, e.g. as shared ancestors or divergence points. Further research into the interpretation of nodes and the role of nodes labeled as 'common ancestor' or as named hypothetical ancestors is needed.

Language and Meaning Making in Science

In his book *Talking Science* (1990), Lemke described the importance of sociocultural elements in considering the use of science language in the classroom; essentially he proposed that words and phrases are context dependent and can vary in their interpretation and meaning. Later, Lemke argued for the consideration of verbal text in the context of diagrams and graphics as part of the broader context of science literacy and education (2004). Additional research has emphasized the need to consider language as part of science learning by explicitly teaching science language and linking everyday and science language (Brown & Ryoo, 2008; Brown & Spang, 2008). Evolutionary concepts and terminology include words that are part of everyday language (Mead & Scott, 2010a, 2010b), and therefore the same words have multiple meanings. This lexical ambiguity makes communicating about science and interpreting learners' explanations about evolution challenging (Nehm, Rector, & Ha, 2010; Rector, et al., 2013).

The role of language in understanding or meaning-making as part of learning includes the function and relationship between colloquial and scientific language. Olander and coworkers (2009; 2010) explored how language is used by high school students to explain variation and selection in an evolutionary context; one linguistic strategy identified by this research is 'transferring,' which connects unknown ideas to known ideas by metaphor. The differences observed in the terminology participants used for branched versus linear depictions of taxa in this study are of particular interest. These differences might reflect participants' existing explanatory frameworks or mental models, and illustrate how a branched tree format might support important, albeit incremental, conceptual change towards a scientifically more accurate interpretation of relationships—shared or common ancestry.

Language and Change – ‘Became’ versus ‘Evolved From’

In this study, participants primarily used the terms ‘evolved/came from’, ‘common ancestor’ and ‘related’ for explanations about branched taxa—e.g. baleen/toothed whales, hippo/whale lineages in both tree formats, and for *Elomeryx*/*Hippopotamus amphibius* in the branched version of the tree graphic. Whereas participants tended to use ‘became’ and referred to a specified ‘ancestor’ for linearly depicted taxa—e.g. *Elomeryx*/*Hippopotamus amphibius* and extinct taxa on the right hand branch in the linear tree format (see Table **9**, Table **18**).

Work with undergraduate students indicates that linear tree graphics are more likely to result in explanations of evolution as anagenic (one entity transforming into another) and teleological (purposeful), and that branched depictions yield more appropriate ancestry explanations (Novick, et al., 2010b). These researchers propose that linear and branched diagrams privilege these alternative interpretations; anagenic or cladogenic. Another study by Catley, Novick and Shade (2010) examined the interpretation and explanation of linear evolutionary representations (non-cladogenic diagrams) by university students and found that linear diagrams elicited anagenic explanations. As part of their coding, they grouped together the following phrases: *evolved from/into/became/evolved out of/through,* which the authors suggest imply an anagenic conception of evolution, one in which taxa change in a direct, linear way from one kind of thing to being a different kind of thing. In addition to the *evolved from/into/became etc.* category, they also created a group for *ancestor/descendant of/to* and another for *common ancestor*—which they think might reflect progressively more sophisticated sets of terms. Their study found that participants were most likely to use *evolved from/into* in their answers, and common ancestry was rarely mentioned.

Participant responses reported in this study suggest that the meaning and usage of the terms in the *evolved from/into/became/evolved out of/through* category study might be more nuanced than Catley et al. (op cit.) suggest—i.e. 'evolved/came from' and 'became' are used in subtly different ways that reflect a small, but important shift in thinking about evolutionary change. In my study, participants generally used 'evolved/came from' and 'related' for explanations of branched taxa and 'became' and a specific 'ancestor' for linearly depicted taxa. Details of participant explanations for the taxa specific questions—branched extant whales, and linear versus branched *Elomeryx* and hippo were contrasted in Table **10**, Table 11 and Table **18**.

The only use of 'became' for a branched depiction of *Elomeryx* and *Hippopotamus amphibius* was made in response to the general question about what kind of things the participant saw in the graphic—but her answer to a later question about what the graphic was trying to show about the specific taxa was that they were 'related' (Melissa, 17, 007, branched tree). This is consistent with the observation that some participants generalized or initial explanations about evolution and the tree graphic often reflected more intuitive reasoning (e.g. use of 'evolved into') than their responses when focusing on specific elements of graphic representation (Table **9**).

The findings from my study indicate that branched depictions facilitate a scientifically more accurate interpretation than do linear representations—i.e. that taxa are related via shared or common ancestry rather than have an ancestor-descendent or anagenic relationship. Therefore, the differences in the language used by participants in their explanations for the different tree formats are important to consider.

'Related' is an adjective that refers to a connection or grouping based on shared qualities. Both 'evolved/came from' and 'became' are relationship statements. The preposition 'from' is used to link and show a relationship between words, referring back to a starting point or source, i.e. something comes or goes away from something else. In the context of an evolutionary tree graphic, it could be interpreted as a shared source for different taxa. The verb 'became' describes an action or state, a relationship in which something undergoes development or change to become something else specific, and 'once was' suggests that one thing previously used to be the other. 'Ancestor' is a noun denoting the progenitor of more recent taxa, and 'common ancestor' an ancestor that two or more descendants have in common.

Lexical decomposition is a linguistics method for characterizing the sense of words by considering features related to their semantic properties or meaning (Parker & Riley, 2009). Table 19 compares the semantic elements of 'evolved from', 'became', 'ancestor' and 'common ancestor'. Perhaps not surprising 'became' and 'ancestor' share many semantic elements as do 'evolved from' and 'common ancestor' since these terms were used in the same context to describe relationships—i.e. the former for linear trees, the latter for branched depictions. Taxa being more or less closely related to each other via common descent or shared common ancestors are scientifically appropriate interpretations of evolutionary relationships—and are phrases with which 'evolved from' shares several important semantic elements, particularly direction and an independent ancestor relationship to other taxa.

Table 19 Semantic features of terms used during participants' explanations (*most cases).

	Change over time	Backward looking	Third Party Ancestor Status
Became	+	-	-
Ancestor	+	+	-*
Evolved From	+	+	+*
Common Ancestor	+	+	+

The observation that terminology varies by graphic depiction suggests that different explanations reflect small but important differences in versions of or ways of thinking about change. If, as Evans and others (Evans, Frazier, et al., 2010; 2013) propose, viewing change as developmental (i.e. transformational) serves as a transitional concept between the idea that change cannot occur and more scientific thinking about evolution—findings from this exploratory study suggests that 'evolved from' might not necessarily always reflect a strictly anagenic, transformational view of change and exclude more cladogenic thinking. In other words, perhaps 'became' and 'evolved from' can be thought of as representing different points along an analogy spectrum of developmental change with branched depictions of taxa supporting a more cladogenic-like interpretation and with 'evolved from' representing an incremental shift away from viewing change as the result of an individual transformation from one thing into another, towards a more scientifically accurate explanation in which taxa (i.e. species) emerge from a shared source.

Metaphors and Ontological Categories

Metaphors are words or phrases that describe one thing in terms of another, and are thought to play a role in science learning by connecting unknown or new ideas to known concepts as part of the meaning-making process (Aubusson, Harrison, & Ritchie, 2006). Metaphors form an important part of evolutionary theory and are of interest with regard to the representation of phylogeny and to an understanding of their limitations and use as tools for teaching and learning about evolution (Brooks & Agosta, 2012; Nehm, et al., 2010; Pramling, 2008). Conceptual Metaphor Theory (CMT) proposes that metaphors link ideas through language—i.e. one concept is understood in terms of another (Lakoff & Johnson, 1980).

There is considerable debate regarding the idea of conceptual or cognitive metaphors and their relationship to words and phrases, and prior work has found that a wide range of variables influence how people use metaphorical language including differences among individuals (e.g. age, culture, prior experience with language), the context in which they are used (e.g. goal or task involved), as well as the kind of metaphor under investigation and the particular strategies used to study them (Gibbs, 2013). Nonetheless, it is worthwhile to consider the potential metaphorical context of the differences in terminology observed in this study between branched and linear depictions of taxa in tree graphics to explore possible links between metaphorical elements and aspects of mental models and conceptual change—e.g. ontology, epistemology.

The meaning or scientific interpretation of the depiction of taxa in an evolutionary tree is relatedness, specifically common ancestry. To understand or interpret the relationships in terms of the verb ‘became’, which describes an action in which something changes into something else, incorrectly reflects an ancestor-descendant one. The term ‘evolved from’ links current or more recent entities to something earlier, and so could be thought of as a more appropriate comparison or connection, but might also indicate an ancestor-descendant relationship in some sense. Since this terminology reflects intuitive reasoning about change, which might serve as transitional concepts to more scientific explanations, it might be more appropriate to think of this language as more analogical rather than metaphorical—but conceptual metaphor research incorporates ideas of metaphor and analogy, and this level of detail is beyond the scope of and data available in this study.

According to Lakoff and Johnson (1980) in their book on the metaphorical nature of language—which was referenced in the Catley et al. (2010) study of undergraduate student explanations of linear representations in evolutionary trees—the use of ‘into’ or ‘out of’ in an expression reflects a change from one state into another such as ‘‘I made a sheet of newspaper into an airplane’’ (p. 73) and ‘‘mammals developed out of reptiles’’ (p. 74). In other words, what was once one kind of thing is now a different kind of thing. If we consider Lakoff and Johnson’s (op cit.) change metaphors in more detail, they describe different types of change/transformation metaphors. A change metaphor in which the *object comes out of the substance*—i.e. 'evolved from'—the object is a type or kind that emerges from a substance. A change metaphor in which the *substance goes into an object*—i.e. 'became'—the object is a container for the material or substance.

The ontological categories and properties of 'entities' as *object* versus *substance* differ in how their structures are related to the kind of thing they are (Figure **22**). To conceive of an entity as an *object* is to view it as a 'kind' with a specific or non-arbitrary structure that results from the kind of thing it is; i.e. its structure is a consequence of the kind of thing it is. *Substance* construal views an entity as 'stuff', the structure of which is arbitrary rather than a function of the 'kind' of thing it is; i.e. something else must be referenced to understand its structure since it is not inherent to its 'kind' (Prasada, Frerenz, & Haskell, 2002).

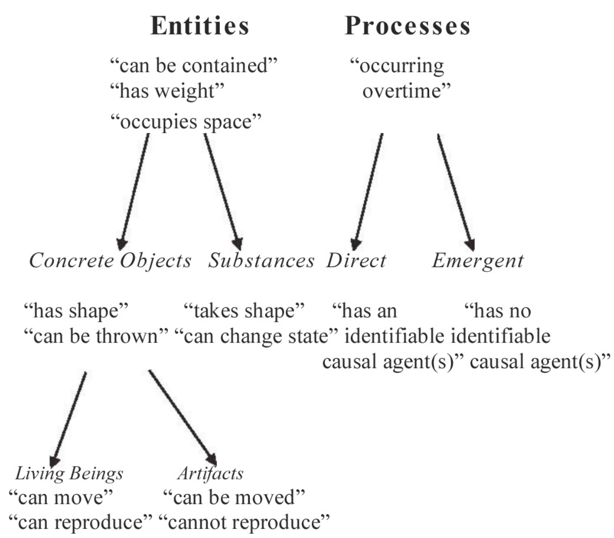

Figure 22 Hierarchical and lateral ontological categories (modified from Chi, 2008).

If we consider the properties of entity categories with the language observed in this study, 'evolved from' describes an *object emerging from a substance* whose properties are independent of its designation as a kind. While 'became' suggests a situation in which a *substance goes into* *an object* or kind. The change metaphor of 'evolved from' could then be thought of as referring to an object or kind (i.e. taxon) that emerges/comes from a more abstract substance or source, and 'became' as describing a change in which a more abstract substance goes into a kind or object. In both cases, the extant taxa—baleen whale, toothed whale and hippo—represent objects, but their origins differ—for 'evolved from' both taxa have a separate or third-party source (i.e. substance properties), and for 'became' a taxon's origin is the transformed substance of an earlier named taxon. The view that tree graphics represent taxa's or objects' connection via shared or common ancestors (a.k.a. substances) can be thought of as more scientifically appropriate for thinking about evolutionary relationships than a transformation of substance into another taxon.

Moreover, these change descriptions appear to differ in terms of their ontological process categories, as direct or emergent. Prior research on evolutionary understanding proposes that ontological category errors can influence common misinterpretations about natural selection—e.g. the idea that selection works on individuals and subgroups rather than the entire population results from students' miscategorization of natural selection as an event or direct causal process rather than an emergent one (Chi, Kristensen, et al., 2012; Chi, Roscoe, Slotta, Roy, & Chase, 2012; Ferrari & Chi, 1998). A direct or event process involves distinct actions by an agent with special status, is intentional and goal-directed, sequential and bounded with a beginning and end. An emergent process is non-sequential, ongoing, and one in which all agents and interactions have equal status (Figure **22**).

Direct processes are linear, intentional and goal-directed; whereas emergent processes are not. If we consider these process properties in the context of change metaphors and the use of 'became' is akin to metamorphosis, for example in Lakoff and Johnson in which 'the caterpillar turned into a butterfly'—then 'became' suggests a directed, goal-oriented, sequential process in which an individual transforms into something else. In contrast, 'evolved from' is a process in which two or more objects emerge from something else; while it is possible that this process might be also be viewed as directed and goal-oriented in some ways, it is not a necessary consequence. Figure **23** summarizes the differences in language used during explanations of branched versus linear depictions within the framework of differing entity and process ontological categories.

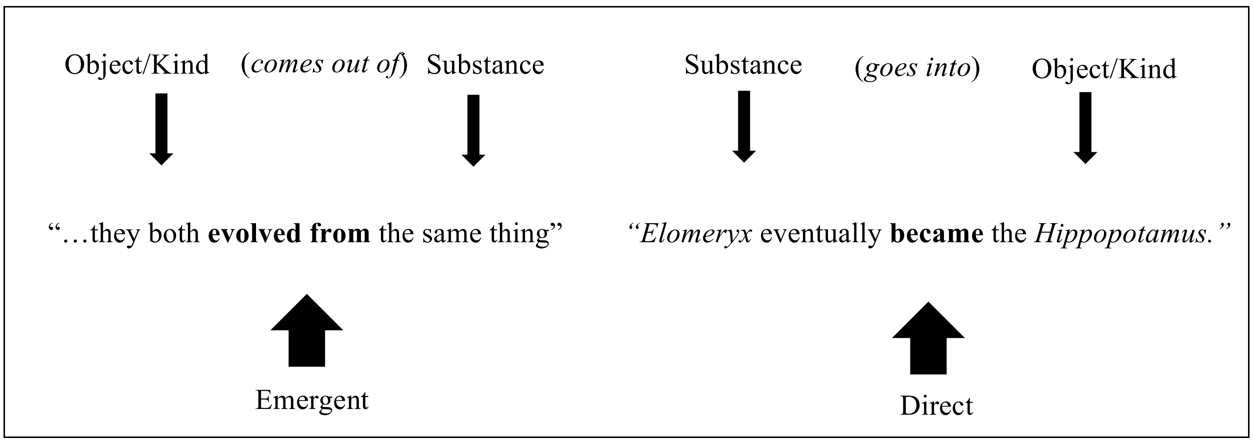

Figure 23 Change metaphor attributes of 'evolved from' (branched depictions) and 'became' (linear depictions) and related entity and process ontological categories.

Analysis of the specific language used by participants in their explanations, therefore, further corroborates the major conclusion of this study. The semantic features of using 'evolved from' to describe relationships and evolutionary change (i.e. backward looking, third-party ancestor status) for branched depictions of taxa and their ontological properties (i.e. emergent)—support the idea that branched tree graphics can help to support a subtle, yet potentially important shift in explanation from a strict linear developmental analogy towards a slightly more scientifically appropriate perspective. Moreover, the use of 'became' for non-branched representations supports the idea that a linear depiction of taxa along a branch reinforces an intuitive view of evolutionary change as a directed, goal-oriented process that occurs via the transformation of an individual taxon into another.

Essentialism and Ontological Categories

The role of essentialism—the idea that biological kinds have some inherent quality that makes them a member of that group, as it relates to categories of living things and the inferences that can be made about them—provides another perspective on the language used during explanations of relationships observed in this study. Essentialism reflects a broad framework with several core components including the idea that category members share deep (often invisible) similarities, and that categories are inferentially rich, immutable, and have an innate development path. These ideas are thought to hinder acceptance of common descent and change between kinds (Gelman & Rhodes, 2012). Essentialist thinking is thought to emerge in childhood and continue until about 10 to 12 years of age (although some ideas persist into adulthood), and can be mediated by an understanding of within-species/kind variation and change (Evans, Szymanowski, Hull Smith, & Rosengren, 2005; Herrmann, et al., 2013; Shtulman & Schultz, 2008).

All participants in this study accepted the ideas of common descent and change between kinds; the idea that organisms are fixed or unchanging was not observed, except for one statement that taxa are 'just here' (participant 005). Previous work has found that people attribute essences to biological organisms at multiple levels simultaneously (Barrett, 2001; Coley, Medin, & Atran, 1997)—i.e. there are multiple types of biological kinds and an individual organism could simultaneously be a member of several, overlapping categories such a poodle belonging to mammal, dog and carnivore. Such categories are inferentially rich, and do not necessarily reflect superficial similarity; members of a given category share a real, internal and even invisible quality (Gelman & Rhodes, 2012).

Coley and Muratore's (2012) summary of folk biological research highlights the finding that most inferences that are made about a taxon (e.g. features) occur at the basic-level (e.g. bird). Superordinate categories (animal) tend to emphasize more abstract or functional features, and subordinate ones (sparrow) more subtle distinctions between very similar objects. Barrett (op cit.) suggested that since shared properties and transmission of characters by common descent result in the hierarchical, nested structure of biological organisms—essences or at least some essences may not be mutually exclusive, "In terms of their inferential properties, essences might behave rather like *substances*: for example, they could be mixed in different proportions in different individuals." (emphasis mine, page 23).

It is possible that when common descent and change are accepted, category membership based on some sense of essences rather than superficial similarity might be helpful for particular aspects of thinking about evolutionary change. In other words, if essences act like substances, then this aspect of essentialist reasoning might lend *substance*-like qualities to thinking about evolutionary change and support a view of taxa as emergent entities. Specifically the use of 'evolved from' as a change metaphor—in which *object comes out of the substance* or taxa emerge from a substance—for branched depictions of taxa in this study suggests that a shift towards a scientifically more accurate interpretation of evolutionary change might be supported if shared ancestors are afforded substance (essence) qualities rather than object ones. It is worth noting that some biologists and philosophers have argued that elements of essentialism are compatible with ideas in evolutionary biology; e.g. morphology is the result of deep, underlying shared properties (Bloom, 2000; Boulter, 2012; Walsh, 2006).

Ancestors as Individuals versus Populations

Another way that essentialist thinking is thought to impact the understanding of evolution is the level at which it operates; the incorrect interpretation that evolutionary change takes place within individuals rather than populations (Gelman & Rhodes, 2012; Shtulman & Calabi, 2012). Elements of ancestor explanations by three participants in age group 2 (aged 14-18), and one participant in age group 1 (aged 11-13) lend further support to the idea that using 'evolved/came from' might not indicate a strict, narrow developmental interpretation of evolutionary change.

Several participants referred to a split or division among members of an ancestral population, such as Andy (aged 12, 010, linear tree) who said " Like half of those animals evolved into *Elomeryx* and half of those [gesture at Artiodactyl ancestor] could have evolved into these [gesture up right branch], whale like things…." and Josh (aged 18, 018, linear tree), who thought that "…some of this animal went in this direction and some of this animal went in this direction [point with both hands at Artiodactyl ancestor, then trace up left branch to *Elomeryx* with left hand, and right branch to *Dorudon* with right]". It is important to note that both participants are referring to that Artiodactyl ancestor near the bottom branched point in both tree formats.

Lucy (aged 14, 012, linear tree) described the whales as being related by a common ancestor, and *Hippopotamus amphibius* has having 'evolved from' *Elomeryx*—the only linear tree user to use that language. In her response to 'how' questions, she referred to a division among a group of ancestors, "By, um – like isolation of different parts of that, um, main, the ancestor or like natural selection and stuff like that [laughs]." Reiterated later "…by different sections of the ancestor getting, separated, or maybe, um, different groups of the ancestor moving into different parts of the world – where they need, um, different traits to survive in different climates…”.

Ellie’s (aged 16, 015, branched tree) explanations also indicated that she viewed ancestors as populations rather than individuals, emphasizing the idea of subgroups of an ancestor or common ancestor. In response to what the graphic is trying to show about *Balaenoptera musculus* and *Tursiops truncatus*, she said, “…They both came originally from a subgroup that also created *Dorudon*.” And for *Elomeryx* and *Hippopotamus amphibius* that “Um, again they came from the same kind of, subgroup both dating back to the Artiodactyl...”

This study did not specifically focus on the nature of ancestors or the evolutionary processes involved in speciation, in part because previous work suggests that tree graphics hinder thinking about natural selection because they do not depict variation (Evans, et al., 2012). It might be worthwhile for a future study of tree graphics to include an in-depth exploration of how visitors or students interpret terminal taxa and unnamed ancestors (e.g. nodes) within the context of common descent explanations.

Detailed consideration and credibility of the potential role and interaction between ontological categorization and essentialist-type explanations in supporting and/or hindering different aspects of tree-thinking is beyond the scope of this exploratory study. This is an area, however, that would be of interest for future research in terms of thinking about transitional concepts, as well as the development of common descent ideas and natural selection, which are thought to have a different cognitive and learning progression (Evans, et al., 2012).

Patterns in Tree Reading and Interpretation

Participant performance on the questionnaire was highly variable. No distinct patterns emerged with regards to the questionnaire responses by age group (11-13, 14-18, adults), but they did for tree format. Branched tree users performed better in terms of overall total and average scores; the range of scores, however, was comparable to linear tree users. Responses to select ancestor items strengthen the interpretations of interview findings that a branched tree depiction might help support more scientifically accurate interpretations of evolutionary graphics—i.e. support the identification of taxa that share the most recent common ancestor. In addition, patterns of responses to relationship and character questions observed in this study suggest additional factors that might play a role in tree reading and interpretation.

Identifying Common Ancestry – Branched versus Linear Trees

Ancestor questions in the questionnaire involved identifying the two taxa that shared a common ancestor most recently or when a shared ancestor would have lived. Participants using a branched tree were significantly ($F=10.125$; $p=0.0051$) more likely to correctly answer one particular ancestor question (see below)—selecting *Hippopotamus amphibius* and *Elomeryx* as the two animals of the pairs listed that share an ancestor in common most recently.

Q1. Which two animals have an ancestor in common most recently? (circle **one** answer)

a. *Rodhocetus* and *Elomeryx*
b. *Rodhocetus* and *Pakicetus*
c. *Balaenoptera musculus* and *Pakicetus*
d. *Hippopotamus amphibius* and *Elomeryx*

Most incorrect responses opted for (a) *Rodhocetus* and *Pakicetus*, the two taxa that are the closest to each other graphically; therefore, proximity might be a factor in participants incorrectly selecting *Rodhocetus* and *Pakicetus* as sharing an ancestor most recently. *Elomeryx* and *Hippopotamus amphibius* are not the closest two taxa either vertically or horizontally.

Branched tree users also were more likely than linear tree users to correctly select *Dorudon* and *Tursiops truncatus* for question 11 (8 out of 10). Of the incorrect responses, all but one selected *Rodhocetus* and *Pakicetus* (see below), which might support the idea that proximity was being interpreted as representing relatedness, at least in linear trees.

Q11. Which two animals have an ancestor in common most recently? (circle **one** answer)

a. *Balaenoptera musculus* and *Rodhocetus*
b. *Dorudon* and *Tursiops truncatus*
c. *Elomeryx* and *Pakicetus*
d. *Rodhocetus* and *Pakicetus*

My interpretation for the stronger performance on these questions by branched tree users is that a linear depiction of relationships obscures the reading/interpretation of shared or common ancestors because the taxa are perceived as having a direct ancestor/descendant relationship. The responses to these two questions by three members of the same family who used different tree formats lends support to the idea that a linear depiction might obfuscate common ancestry interpretations. Linear tree users Thomas (aged 45, 003) and Peter (aged 16, 002) answered these questions incorrectly; whereas Judy (aged 42, 004), who used the branched tree, selected the correct option for both questions.

If linear depictions confuse or obscure identification of shared/common ancestors, then we need to consider why linear tree users might have performed better on question 11 compared to question 1 (5 versus 2 correct responses, respectively)—both of which asked participants to select the two animals that have the most recent common ancestor. On the linear tree, *Dorudon* is located at/near the branching point or node of *Balaenoptera musculus* and *Tursiops truncatus*. If a given taxon is thought of as being most closely related to its perceived ancestor, then the pattern of responses to these two questions between branched and linear tree users would be consistent with this. Branched tree users correctly selected *Dorudon* and *Tursiops truncatus* as sharing a common ancestor most recently, linear tree users chose the same option but for different reasons—because 'ancestor' and 'common ancestor' have become conflated since a named taxon is placed at the node. A study in which participants provided explanations for their choices would be able to investigate this possibility.

<u>Interpreting Relationships and Characters – Ancestors versus Descendants</u>

The pattern of incorrect responses to relationship and character questions suggests a potential ancestor bias—i.e. taxa are more closely related or connected to, and are more likely to share characters with ancestors or earlier taxa than with descendants. Relationship questions asked participants to identify the animal that is most closely related to the stem taxon (questions 2 and 10); incorrect responses typically involved participants selecting the ancestor/shared ancestors of the named taxa in the stem rather than the appropriate more recent/descendant taxa. Participants might then be interpreting a given taxon as being more closely related to its ancestor or taxon that they shared an ancestor with in the past (depending on how they interpret the relationship between taxa) than to one with which they share a more recent ancestor. This could, however, reflect reading proximity as relatedness—a common tree reading error.

When questions asked about a specific taxon's relationship to two other taxa (questions 4 and 7), many respondents incorrectly opted for them to be equally related to two other taxa—another common misinterpretation—others incorrectly selected an option in which the stem taxon was more closely related to or only related to its nearest ancestor/shared ancestor. One of these questions refers to taxa on both sides of the graphic, and while it was answered correctly by both linear and branched tree users, incorrect responses identified taxa that were graphically closer in the tree as being related, but also excluded taxa on the other side (i.e. indicated that it was not related to the stem taxon). It is possible that proximity played a role both in selecting the correct answer (i.e. because they are on the same side) in some cases, as well as incorrectly excluding the more distantly related taxon on the other side of the tree.

Halverson et al. (2011) found that university students often use node counting as a strategy to determine relatedness, that is, they selected the most closely related taxon based on the number of nodes between them—fewer nodes indicating a closer relationship. In this study, node counting would also result in selecting an earlier taxon with shared ancestry that is one node away if a later taxon (e.g. extant) is two nodes away. Incorrect answers to relationship questions that asked participants to identify the animal that was most closely related to the stem taxon (e.g. see question 2 below) could reflect node counting since *Pakicetus* is one node away from *Rodhocetus* while *Balaenoptera musculus* is two; these taxa, however, are also the closest in terms of proximity, and therefore this might also be a factor. Responses in which participants selected the 'equally related' option could represent node counting since it would be one 'step' or node in either direction (e.g. see question 4 below), but not necessarily in proximity.

Q2. Which animal is *Rodhocetus* most closely related to? (circle **one** answer)

a. *Pakicetus*
b. *Elomeryx*
c. *Balaenoptera musculus*
d. *Hippopotamus amphibius*

Q4. Which of the following is an accurate statement of relationships? (circle **one** answer).

a. *Dorudon* is related to *Rodhocetus*, but is not related to *Tursiops truncatus*
b. *Dorudon* is more closely related to *Tursiops truncatus* than to *Rodhocetus*
c. *Dorudon* is more closely related to *Rodhocetus* than to *Tursiops truncatus*
d. *Dorudon* is equally related to *Tursiops truncatus* and *Rodhocetus*

While node counting and proximity have been found to influence interpretation of relationships, the pattern of responses to question 10 (see below) lends support to the idea that incorrect answers might reflect an interpretation that a given taxon is more closely related to earlier taxa, i.e. its ancestor or shared ancestor, than to descendants or later taxa. All incorrect responses (n=7) to question 10 chose *Dorudon* as being most closely related to *Balaenoptera musculus* even though *Tursiops truncatus* is graphically closer.

Q10. Which animal is *Balaenoptera musculus* most closely related to? (circle **one** answer)

a. *Hippopotamus amphibius*
b. *Tursiops truncatus*
c. *Elomeryx*
d. *Dorudon*

Of the 13 participants who correctly selected its extant sister taxa (*Tursiops truncatus*), nine used a branched tree format in which *Dorudon* is located at a separate terminal branch point rather than at the baleen and toothed whale node (although it retains the same vertical proximity in both tree formats). Branched depictions then might help to undermine an intuitive misinterpretation that taxa are more closely related to their ancestors than to their descendants. In the linear version of the tree *Dorudon* is at the node and so could be interpreted as being fewer nodes away from *Balaenoptera musculus* than *Tursiops truncatus*; this would not be the case in a branched tree format. Proximity does not appear to fully explain the pattern of responses by linear tree users—and while vertical proximity between taxa does not differ between tree graphics (although horizontal proximity does), the number of nodes separating the taxa does.

A question asked by Josh (aged 18, 018, linear tree) while completing the questionnaire provides some additional context—he asked if I wanted 'the living one' for the answer to which animal *Rodhocetus* is mostly closely related to (question 2, see above). Josh was told that he could select a taxon that was living or one that was not, and that I wanted the animal that he thought *Rodhocetus* was most closely related to; he incorrectly selected *Pakicetus*, as did all other participants. Therefore, ancestors or shared ancestors of a given taxon might be viewed as being more closely related than descendants. It might also be the case that relationships among extant and extinct taxa are interpreted somewhat differently—as indicated by the more frequent usage of the term 'relatedness' or 'relationship' when referring to extant taxa (see earlier discussion).

It is also possible that proximity and node counting contribute to varying extents in different situations. They do not, however, appear to adequately address the interpretation of shared characters observed, which was similar to that seen with relationship questions—participants identified and interpreted ancestors/common ancestors of a named taxon as possessing a particular character or trait, but often excluded later or descendant taxa. For example in question 12 (see below) all participants correctly identified *Dorudon*, an ancestor/common ancestor of *Balaenoptera musculus*, as having the shared character, but many missed *Tursiops truncatus*.

Q12. If a fossil whale from 40 million years ago, *Balaenoptera musculus* and *Rodhocetus* were found to have similar skull bones, what other animals would you expect to have the same trait? (circle **all** correct answers).

a. *Dorudon*
b. *Elomeryx*
c. *Pakicetus*
d. *Tursiops truncatus*

Excluding descendant taxa for character questions could reflect a distinction between tree reading and the inferences that can be made about the hierarchical relationships of taxa in evolutionary trees and their features, and inferences made using more intuitive reasoning about organisms. For example, folk generic categories provide a basis for making inferences about the properties of organisms—and in some groupings not all properties of superordinate groups are necessarily inherited by subordinates (Coley & Muratore, 2012). In other words, not all properties of ancestral species are found in descendant species, which might create an obstacle to thinking about shared characters within the context of common descent—if different life-form categories are perceived at different points in a tree graphic resulting in a subset of taxa or lineage being viewed as disconnected from others (e.g. whales and not-whales). It is also possible that selection related ideas might contribute to identifying ancestors as possessing traits but not descendants—e.g. the idea that characters can change over time emphasizes different rather than shared traits in descendant taxa. This study did not investigate the idea of folk biological categories or natural selection ideas as they relate to evolutionary change and/or traits, but it might be a productive area for future research.

Learning Progressions Revisited

In this study, participants of all ages accepted the idea of common descent and that one kind can change into another, and also used mixed reasoning in their explanations. Although there was little difference in terms of questionnaire performance by age group; members of the youngest age group (aged 11-13) consistently used needs-based reasoning, struggled with ‘how’ questions, and were less likely to provide much detail or incorporate evolutionary ideas (e.g. variation, selection, inheritance, time) into their explanations.

Table **20** situates this study within the context of existing literature about the development of evolutionary ideas. Previous research indicates that mixed reasoning is common, and want-based reasoning is more frequently seen in early elementary aged students with a transition towards needs-based reasoning—thought to be an important first step—occurring in older elementary students. My findings are consistent with and support this prior work, which found that tree graphics elicit ideas of common descent, relationships and ‘change of kind’, and few references to natural selection and the VIST principles—variation, inheritance, selection and time.

This research extends previous work by exploring tree-related reasoning patterns and evolutionary ideas with older youth and adults. Common patterns observed in all age groups were references to evolutionary change occurring over time and the idea that taxa change to meet their needs, which typically result from changes in external factors. While members of all age groups demonstrated needs-based reasoning; ideas of want' and taxa 'choice' linked to need were uncommon and only observed in two participants (aged 11 and 15). External factors, typically the result of changes in the environment, were described as the reason for evolutionary change across all groups. Such reasoning appears to be persistent, as demonstrated by a 2013 study that found that undergraduate students use 'need' in a teleological sense (e.g. 'had to'), and describe adaptation as an individual adjustment to an environmental change (Rector, et al., 2013). In this study, references to variation, selection and inheritance were uncommon and only observed in a few participants, mostly in the older age groups (aged 14-18 and adults).

Evans et al. (2012) proposed a general developmental learning progression for evolution (Table **21**) in which common descent is initially viewed as not possible or the result of a proximate cause. This no-change reasoning transitions to change being possible and viewed within the context of a developmental analogy—the idea that change results from innate potential like growth and metamorphosis—and then later moves towards an evolutionary explanation. In essence, Evans and others (Evans, et al., 2012; Legare, Lane, & Evans, 2013) argue that needs-based reasoning and viewing change within a developmental framework serve as transitional concepts between an initial intuitive essentialist perspective (i.e. taxa cannot change) and ideas about change as intentional (i.e. taxa want to change)—and more scientifically accurate evolutionary explanations (e.g. change is not the result of need, change occurs in populations rather than individuals).

In terms of tree format, a visitor study by Evans et al. (2010) found that the whale graphic used in this study (linear version) elicited such transitional reasoning, i.e. needs-based and developmental change—and other studies have found that linear depictions prompt anagenic and teleological reasoning, i.e. transformation from one taxon into another, and needs-based

Table 20 Summary of studies about learning progressions for evolution.

<table>
<tr><th rowspan="2"></th><th colspan="11">Age</th></tr>
<tr><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14-18</th><th>adults</th></tr>
<tr><td>Evans, et al. (2000, 2001, 2008, 2012)</td><td colspan="3">• Creationist/spontaneous generation reasoning
• Essentialism
• Proximate cause</td><td colspan="2">• Creationist reasoning
• Needs-based
• Distal cause

More likely to accept within species variation & change; less likely to accept common descent/one kind from another</td><td colspan="3">• Creationist, evolutionary & mixed reasoning
• Needs-based; 11-12 Lamarckian

More likely to accept common descent/one kind from another</td><td colspan="3"></td></tr>
<tr><td>Samarapangavan & Wiers (1997)</td><td colspan="4"></td><td colspan="3">Various reasoning: essentialist; microchange; creationist; Lamarckian; mixed</td><td colspan="4"></td></tr>
<tr><td>Berti et al. (2010)</td><td colspan="2"></td><td colspan="3">Creationist (most 7-8), evolutionary & mixed reasoning (most 8-9)</td><td colspan="6"></td></tr>
<tr><td rowspan="2">This study</td><td colspan="6" rowspan="2"></td><td colspan="5">* Creationist, evolutionary and mixed reasoning

Accept common descent/one kind to another</td></tr>
<tr><td colspan="3">• Needs-based; few combined with elements of want/choice
• External factors (e.g. environment)
• Some change over long time & rate (T)</td><td colspan="2">• Needs-based
• External factors (e.g. environment)
• Some change over time (T); variation (V), selection (S); few inheritance (I)</td></tr>
</table>

explanations (Novick, et al., 2010b). My research builds on this work by exploring the potential role of a branched depiction of taxa with all taxa placed at individual terminal branch points in supporting a more scientifically accurate view of evolutionary change; i.e. not as a strictly developmental, linear or transformational process.

Differences in the terminology used and explanations given between the linear and branched tree formats suggest that branched graphics support more scientifically appropriate reasoning than linear representations. Linear depictions of taxa resulted in anagenic-type explanations—i.e. change from one entity into another, as was found in the original study of the whale graphic (Evans, 2010)—and the use of associated transformational language such as 'became'. Branched depictions of taxa were likely to elicit references to taxa as being 'related' and having 'evolved from' something else rather than being the result of one specific taxon becoming or turning into another, as well as cladogenic-type explanations—i.e. the idea that speciation or evolutionary change is the result of splitting/separation/divergence.

Therefore, this study suggests that a spectrum of change thinking might exist within the transitional *developmental change* analogy from a 'change within kind' (transformation from one thing into another) to a 'change between or of kinds' in which one or more taxa originate/come from earlier, but separate and different kinds—although not necessarily reflecting a fully scientific conception of evolutionary change. Moreover, representing the relationships among taxa by using a branched format and placing them at individual terminal end points, as opposed to linearly along branches, appears to support a transition—albeit an incremental one—from a strict linear transformational (anagenic) view of evolutionary change towards a more scientifically accurate one.

Table 21 Common Descent Learning Progression (based on Evans, 2012); * proposed spectrum within developmental change analogy thinking.

Everyday Concepts (cultural & intuitive ideas)	Transitional Concepts (appears ~ age 10-12)	Scientific Concepts
Essentialism	Needs-based language	Darwinian Evolution
Proximate Cause	Developmental change *change within kind ⟷ change between/of kinds	
Intentionality	Mixed Intuitive/Evolutionary Concepts	

Summary of Findings & Interpretations

This exploratory qualitative study focused on visitors' interpretations of two versions of an evolutionary tree graphic to investigate three research questions—how taxa placement as a result of a linear or branched depiction might (i) influence narratives about phylogenetic trees, (ii) affect the reading and interpretation of tree graphics, and (iii) whether the relationships between these factors vary by age.

The findings that emerged from this research indicate that branched depictions of evolutionary relationships can influence narratives about the relatedness of taxa and the nature of those relationships, as well as explanations of evolutionary change—and some aspects related to correctly reading and interpreting tree diagrams, specifically the identification of shared or common ancestry. Branched tree graphics appear to support scientifically more accurate interpretation of relationships than do linear representations—i.e. that taxa are related via shared or common ancestors rather than have an ancestor-descendant or anagenic relationship. Moreover, reasoning patterns were found to be broadly similar among participants in all age groups (aged 11 through adult); older youth (aged 14 to 18) and adults typically provided more detail in their explanations and sometimes included references to informed evolutionary ideas (e.g. variation, inheritance and selection).

Although the results and interpretations should be considered within the contextual framework and exploratory nature of this research, this qualitative study provides additional information and important detail about visitors' ideas and explanations of tree graphics, as well as the role of graphic design in influencing those interpretations. In addition, the findings highlight several areas in need of additional investigation, which are addressed in the following section.

CHAPTER VII: IMPLICATIONS AND FUTURE WORK

This exploratory study informs our knowledge of visitor understanding of evolutionary tree graphics and the role of tree design in supporting scientifically appropriate interpretations of phylogenetic diagrams. It also provides valuable context for thinking about educational practice, and highlights several areas worthy of further investigation as well as new research questions that might help to clarify the complexities of understanding evolutionary ideas and supporting conceptual change.

Implications for Tree Design and Science Education

Differences in participant explanations between the linear and branched graphic depictions of taxa in the whale evolutionary tree reinforce and further emphasize the need to use trees with branched rather than linear arrangements to help facilitate scientifically accurate descriptions and reasoning about the relationships between taxa. Specifically, branched trees appear to help support the idea of evolutionary change as cladogenic (i.e. speciation through divergence, taxa are related through shared ancestors) as opposed to anagenic (i.e. linear transformation from one taxa into another, taxa have a direct ancestor-descendant relationship) and to emphasize the idea of relatedness and common ancestry. Importantly, this appears to be the case for novices or young learners who have had little or no experiences with these ideas, as well as individuals who have had some exposure to these topics (e.g. through formal learning).

In addition, this study suggests that it is important to consider the language used as part of evolutionary narratives by learners (and educators) to gain a better understanding of learners' use and meaning of particular terms in this context, and specifically to address common misinterpretations associated with linear depictions as part of biology teaching. The latter recommendation is particularly valuable given the frequency of linear depictions in textbooks, informal science settings and popular culture, and its resonance with intuitive thinking about evolution—as highlighted by the mismatch between participants' description of explanations learned in school and their narratives in the informal science setting of this study. Finally, the findings suggest that it would be helpful to explicitly address nodes and what they represent as part of communicating about evolutionary tree graphics.

Although trees are not thought to support reasoning about natural selection, the findings of this study suggest that it might be valuable to explicitly teach about evolutionary change (e.g. populations versus individuals, mechanisms of change) earlier in learning. Participants in the youngest group (aged 11-13) endorsed common descent and the idea of change over time, and also demonstrated transitional needs-based reasoning. They struggled, however, to tie their ideas about relatedness, common descent and change to VIST (variation, inheritance, selection, time) concepts—something that is emphasized in the Next Generation Science Standards (NGSS Lead States, 2013b).

Finally in terms of graphic interpretation, educators should be cognizant that (1) learners might view or describe relationships among taxa differently depending on whether some or all of the taxa represent groups that are living or extinct, i.e. relationships among extant taxa might be described differently than between extinct and extant ones, and (2) the identification of the most recent common ancestor and interpretation of shared characters in descendant taxa (at least in a tree graphic in which extant and extinct taxa are present) appears to be challenging.

Future Work

Several findings emerged from this work that warrant further research to clarify and refine these interpretations and inform the following additional research areas.

- Explore the reasoning used by participants with regards to particular questionnaire responses, e.g. how a branched versus linear depiction influences the identification and interpretation of ancestors/shared ancestors.
- Explore the interpretation of common ancestry and its connection to shared characters, specifically why descendant taxa were often not identified as having a shared character.
- Prior work has found that reasoning about evolution often differs by taxa, with many people being more likely to accept evolutionary change if taxa are more distantly related to humans. In this study, a few participants agreed to a lesser extent with evolution as an explanation for the origins of insects than for birds and humans—it would be interesting to explore their reasons for this; e.g. is it because insects are often not considered animals?
- Investigate the apparent differences in visitor explanations for relationships among extant taxa compared to between extant and extinct taxa, as well as the potential influence of representing these relationships using a time-calibrated tree graphic (e.g. whale tree used in this study).
- Investigate evolutionary explanations in school-aged learners, specifically comparing reasoning patterns for taught narratives about evolution (i.e. classroom examples) to explanations used for novel examples outside of a formal classroom setting.

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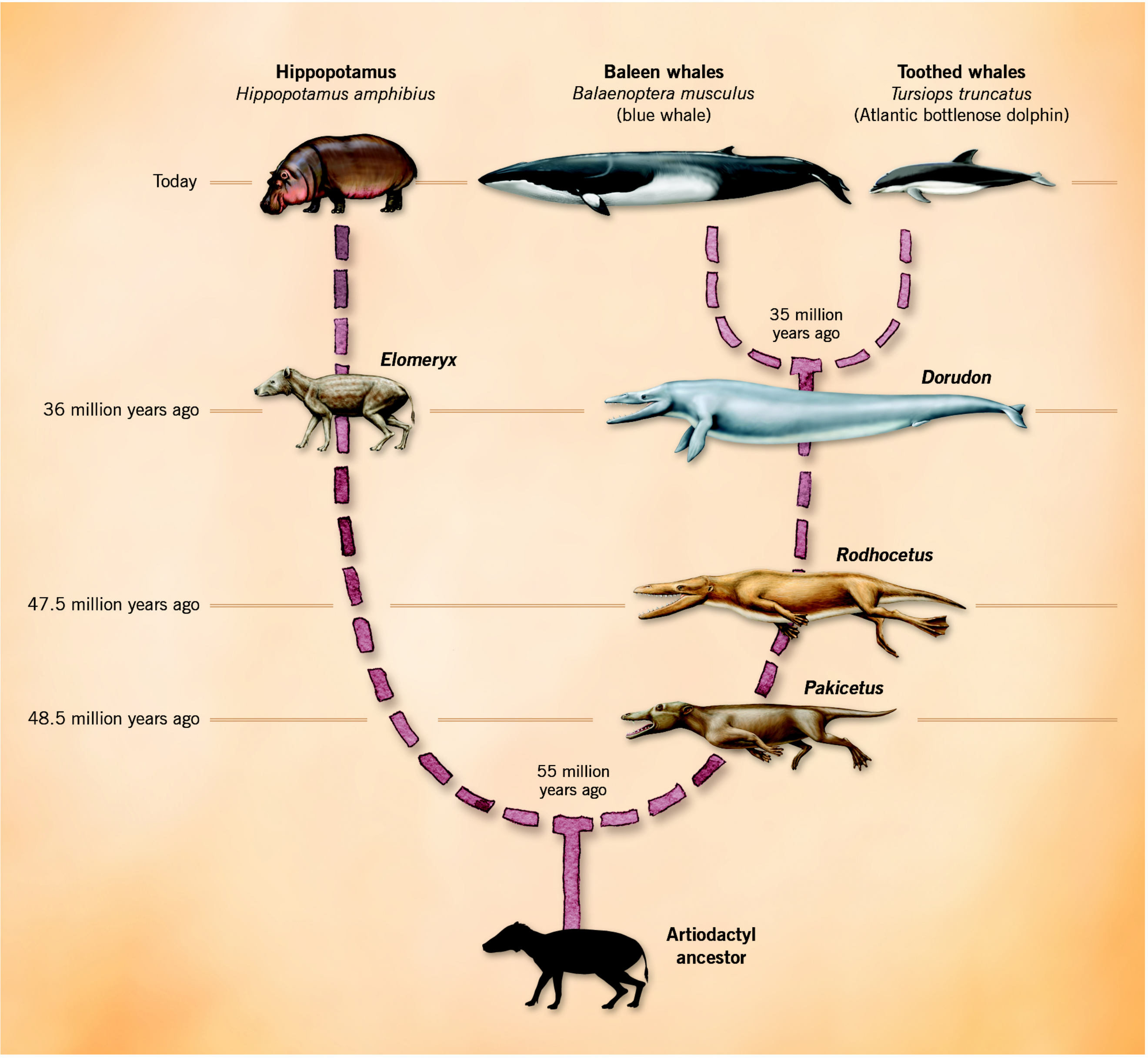
Appendix A. Whale Tree Graphic—Linear Depiction

(minus title and explanatory text)

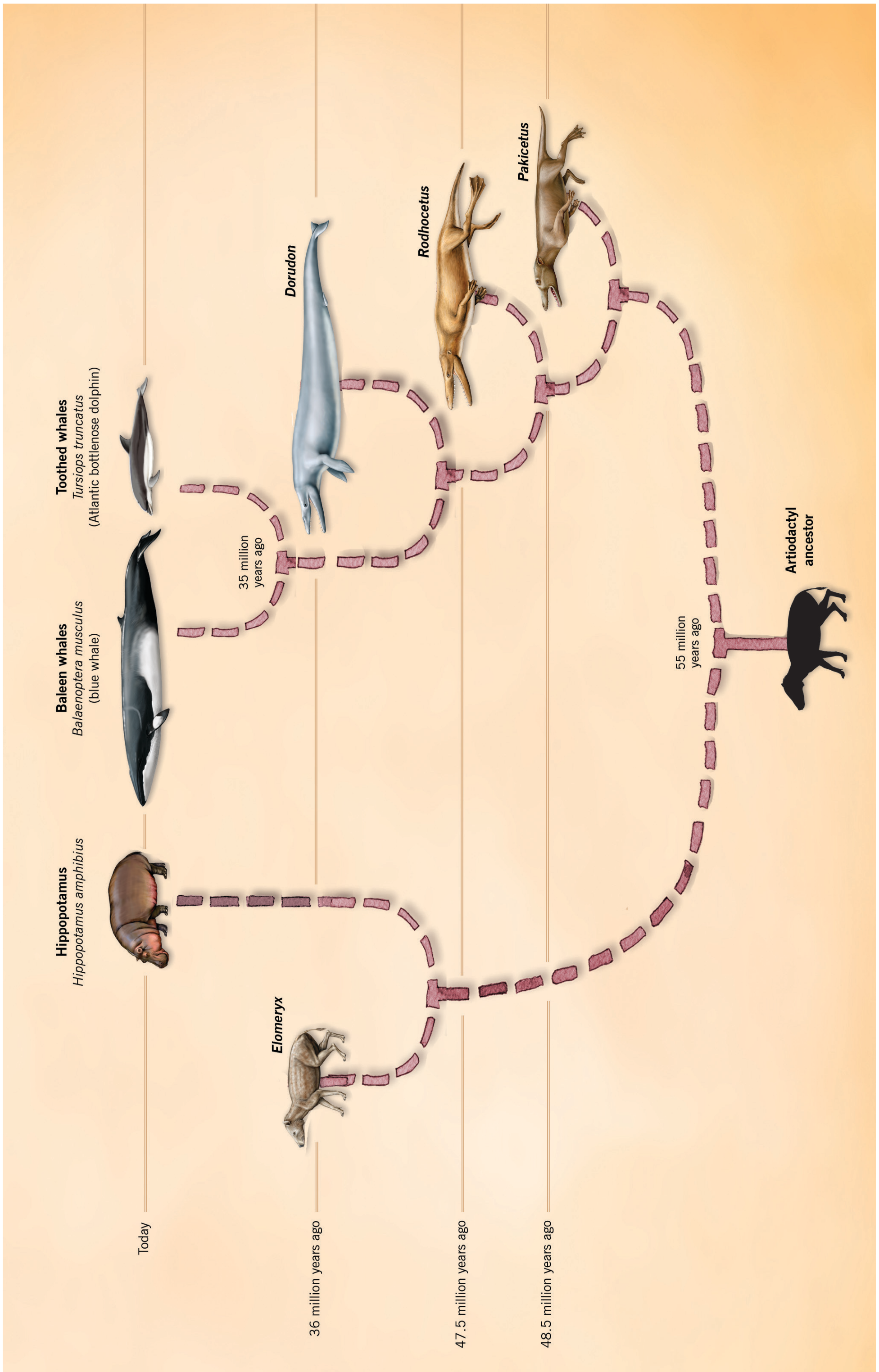


Explore Evolution, whales and close relatives, 2005. SMM illustration, ancient whales John Klausmeyer illustration, modern whales and hippo Adam Wiens illustration.

Pronunciation: *Elomeryx* (E-LO-mer-iks); *Hippopotamus amphibius* (HIP-poh-POT-uh-muhs am-FIB-ee-uhs); *Pakicetus* (PACK-ih-SEE-tuhs); *Rodhocetus* (Road-hoe-SEE-tuhs); *Dorudon* (DOR-oo-don); *Balaenoptera musculus* (bah-lee-NOP-teh-ruh muhs-KU-luhs); *Tursiops truncatus* (tur-SEE-ops TRUN-kah-tuhs).

Appendix B. Whale Tree Graphic—Branched Depiction

(revisions—lineage branches were added to outside of graphic; retained vertical taxa location except for Artiodactyl ancestor, which was moved down to accommodate bottom node needed)



Appendix C. Museum Graphic Questionnaire

Museum Graphic Questionnaire

I would like to learn more about your ideas. All your answers will remain confidential, and no names will be used in any reports.

PART A – Use the graphic provided to answer the following questions.

1. Which two animals have an ancestor in common most recently? (circle **one** answer)
   a. *Rodhocetus* and *Elomeryx*
   b. *Rodhocetus* and *Pakicetus*
   c. *Balaenoptera musculus* and *Pakicetus*
   d. *Hippopotamus amphibius* and *Elomeryx*

2. Which animal is *Rodhocetus* most closely related to? (circle **one** answer)
   a. *Pakicetus*
   b. *Elomeryx*
   c. *Baleanoptera musculus*
   d. *Hippopotamus amphibius*

3. If a fossil whale from 54 million years ago, *Hippopotamus amphibius* and *Tursiops truncatus* were found to have similar wrist bones, what other animals would you expect to have the same trait? (circle **all** correct answers).
   a. *Pakicetus*
   b. *Elomeryx*
   c. *Rodhocetus*
   d. Artiodactyl ancestor

4. Which of the following is an accurate statement of relationships? (circle **one** answer)
   a. *Dorudon* is related to *Rodhocetus*, but is not related to *Tursiops truncatus*
   b. *Dorudon* is more closely related to *Tursiops truncatus* than to *Rodhocetus*
   c. *Dorudon* is more closely related to *Rodhocetus* than to *Tursiops truncatus*
   d. *Dorudon* is equally related to *Tursiops truncatus* and *Rodhocetus*

5. When did *Elomeryx* and *Rodhocetus* have an ancestor in common most recently? (circle **one** answer)
   a. About 55 million years ago
   b. Between 48.5 and 47.5 million years ago
   c. Between 47.5 and 36 million years ago
   d. Less than 35 million years ago

6. If the ancestor of *Rodhocetus* evolved a specific trait, which animals would you expect to have the same trait? (circle **all** correct answers)
   a. *Elomeryx*
   b. *Dorudon*
   c. *Tursiops truncatus*
   d. Artiodactyl ancestor

Museum Graphic Questionnaire

7. Which of the following is an accurate statement of relationships? (circle **one** answer)
   a. *Elomeryx* is equally related to *Pakicetus* and *Hippopotamus amphibious*
   b. *Elomeryx* is related to *Hippopotamus amphibius,* but is not related to *Pakicetus*
   c. *Elomeryx* is more closely related to *Pakicetus* than to *Hippopotamus amphibius*
   d. *Elomeryx* is more closely related to *Hippopotamus amphibius* than to *Pakicetus*

8. How old would the ancestor that *Balaenoptera musculus* and *Rodhocetus* have in common most recently be? (circle **one** answer)
   a. Between 36 and 35 million years ago
   b. Between 47.5 and 36 million years ago
   c. Between 47.5 and 55 million years ago
   d. About 55 million years ago

9. If the ancestor of *Dorudon* evolved a specific trait, which animals would you expect to have the same trait? (circle **all** correct answers)
   a. *Pakicetus*
   b. Artiodactyl ancestor
   c. *Balaenoptera musculus*
   d. *Hippopotamus amphibius*

10. Which animal is *Balaenoptera musculus* most closely related to? (circle **one** answer)
    a. *Hippopotamus amphibius*
    b. *Tursiops truncatus*
    c. *Elomeryx*
    d. *Dorudon*

11. Which two animals have an ancestor in common most recently? (circle **one** answer)
    a. *Balaenoptera musculus* and *Rodhocetus*
    b. *Dorudon* and *Tursiops truncatus*
    c. *Elomeryx* and *Pakicetus*
    d. *Rodhocetus* and *Pakicetus*

12. If a fossil whale from 40 million years ago, *Balaenoptera musculus* and *Rodhocetus* were found to have similar skull bones, what other animals would you expect to have the same trait? (circle **all** correct answers).
    a. *Dorudon*
    b. *Elomeryx*
    c. *Pakicetus*
    d. *Tursiops truncatus*

Museum Graphic Questionnaire

PART B – Please answer the following questions to help us better understand who participated in our study.

1. How many times a year do you visit museums? _______

2. What is your age? _______years 11. What is your sex? ☐ Female ☐ Male

3. Select the ethnic category with which you most closely identify.

   ☐ Hispanic or Latino ☐ Not Hispanic or Latino

4. Select one or more racial categories with which you most closely identify?

   ☐ White ☐ Asian ☐ American Indian or Alaska Native

   ☐ Black or African American ☐ Native Hawaiian or Other Pacific Islander

5. If you are a K-12 student, what grade are you in? ________

6. If you are not a K-12 student, what level of education have you completed?

   ☐ High School ☐ Undergraduate Degree ☐ Graduate Degree

7. If you have or are studying for a university or college degree, what is/was your area of study?

   ____

Please go to the next page

Museum Graphic Questionnaire

PART C – Please answer the following questions to help us better understand your ideas (circle answer).

1. Do YOU think that evolution explains the origin of insects?

   Disagree Mostly Disagree Neither Mostly Agree Agree

2. Do YOU think that evolution explains the origins of humans?

   Disagree Mostly Disagree Neither Mostly Agree Agree

3. Do YOU think that evolution explains the origins of birds?

   Disagree Mostly Disagree Neither Mostly Agree Agree

4. How important is it for scientists to study evolution?

   Not important A little important Pretty important Very important

5. How important is it for YOU to know about evolution?

   Not important A little important Pretty important Very important

6. How much do YOU know about evolution?

   Not much A little bit Some Quite a bit A lot

Appendix D. Participant Profiles – Case Summaries

Descriptions of individual participants are given below using pseudonyms along with their age, corresponding participant number and the tree design they used during the study. These profiles provide information about the sample distribution and context of the individual participants (cases).

Megan (aged 11); Participant 001 – linear tree

Megan is a White non-Hispanic/Latina female, aged 11, in grade five. She recalled having been in the interview space for a museum summer camp a couple of years ago, but did not recall that I was her instructor. She was quick to answer questions and appeared confident in her responses. Overall, Megan's responses during the interview and relevant questionnaire items indicated that she supports the idea of evolution; agreeing with evolution as an explanation for the origin of insects, humans and birds, and that evolution is *pretty important* to know about. She reported her knowledge of evolution as *some* and scored 5 out of 12 on the questionnaire. She did not use the word evolution itself, but did use the verbs *evolve* and *evolving*, and mentioned time as a feature of the graphic.

In terms of 'how' questions, she suggested that evolution results from different needs such as being able to swim—to spread out to different habitats, and that different habitats require different things. How much change had occurred among the taxa in the tree was something she specifically noted about the graphic, comparing and contrasting the taxa in terms of size (e.g. that one had shrunk from its ancestor, and the presence or absence of legs).

Megan described the three extant taxa as evolving from the Artiodactyl ancestor, and the whales as evolving from the same creature that she identified as *Dorudon*—and referred to later/descendant taxa as 'different, although coming from the same thing'. In contrast, she described *Elomeryx* and *Hippopotamus amphibius* more as a transformational sequence in which the former ‘became’ the latter.

Peter (aged 16); Participant 002 – linear tree

Peter is a White non-Hispanic/Latino male, aged 16, in the tenth grade. Peter seemed somewhat reticent during his initial participation, giving quick, short responses during the youth assent procedures and explanation about the questionnaire, as well as the interview itself. Overall, the interview felt a bit rushed at the beginning, and he made little eye contact; however, as the interview continued, he engaged more with the graphic in terms of gesturing and pointing, and appeared to become a little more comfortable talking.

Peter talked about ancestors, things being related, and mentioned mutations multiple times. He also described how these mutations become so great that the taxa can no longer be considered the same species. His explanation of ‘how’ change occurred was that different stimuli and mutations made a select group of individuals more suited and that this kept happening over millions of years, and that species become separated or things split off into different species. Although Peter did not refer to needs or requirements, rather he described mutations that fit the stimuli.

Despite the use of more informed reasoning (e.g. variation and selection), his explanations varied and seemed somewhat conflicted. For example, Peter described the branched depictions of whales as being related to each other and also to the hippo, and the overall tree as showing the relationships between the three extant taxa and their common ancestor, but then also described the Artiodactyl ancestor as ‘becoming’ the whale. In addition, he initially said of the linear depiction on the left branch that *Hippopotamus* once was a type of *Elomeryx*, but then described that something happened and a mutation occurred resulting in the hippo splitting off and *Elomeryx* becoming extinct.

Thomas (aged 45); Participant 003 – linear tree

Thomas is a White non-Hispanic/Latino, aged 45, with a graduate degree in humanities. He is Peter's (participant 002) parent, the spouse of Judy (participant 004), and his daughter had participated in museum summer camps. Thomas was very supportive of evolution and communicating about evolutionary ideas to the public, and described the graphic and its perceived purpose as 'great'. Although interested in evolution, he expressed a perceived limitation on his ability to talk about it as he reflected on his explanations versus the words and phrases a scientist might use, and on the difference and challenges between knowing about something and being able to explain it out loud.

Thomas used the terms ancestor, related, natural selection, generations and other familial language (e.g. grandparents, cousins), and talked a lot about time. He gave environmental explanations for change and described the process as "lots of things were tried and didn't work out" until eventually they look different. He referred to the hippo as the direct descendant of *Elomeryx* and extinct taxa along the right branch as direct descendants of each other, and described being able to see continuity on the right side. References to a split or division were used in his explanation of the two extant whales (baleen and toothed) being related but distinct, and when commenting on a separation that occurred at the bottom node (i.e. Artiodactyl ancestor) and expressing an interest in earlier splits while pointing at the terminal taxa.

Judy (aged 42): Participant 004 – branched tree

Judy is a White non-Hispanic/Latina female, aged 42 with a graduate degree in the humanities. She was very engaged with the graphic, gave detailed responses and was interested in how scientists know and what evidence they used to determine the relationships, as well as what is not yet known.

Judy referred to common ancestors, evolution, adaptation, time, procreation and generations. She provided examples of hypothetical features to explain variation and change—mentioning the environment and accidents as factors—and described a trend towards land for the taxa on the left branch and water for the right branch. Judy described taxa as being related and 'evolving' or 'evolved from' ancestors with splits from ancestors at multiple points—e.g. whales are related and split from an ancestor, and *Elomeryx* and hippo had a common ancestor.

She noted an overall continuity of left and right lineages but with distinct taxa. Judy reflected on, and was somewhat frustrated by, what she thought was represented by the nodes and at different points along branches—e.g. what the *Elomeryx*/hippo node would be and whether *Pakicetus* is at the node as well as the terminal branch point. Ultimately she felt that the taxa had common ancestors and that ancestors evolve into other taxa; although, importantly that the nodes/ancestors are different from terminal taxa. For example, while the Artiodactyl ancestor evolves into *Pakicetus*, the *Pakicetus* node, the original ancestor (Artiodactyl ancestor) and the terminal taxa are distinct taxa.

Carol (aged 44); Participant 005 – linear tree

Carol is an Asian non-Hispanic/Latina female, aged 44, with a graduate degree in science. Carol seemed somewhat hesitant during the interview, providing short and often uncertain answers that necessitated follow up questions and further prompts for most questions. She used the term evolution, cousins and time occasionally, and qualified her single use of 'ancestors' with 'so to speak'. This apparent reluctance or lack of engagement might reflect a mixed or somewhat conflicted view of evolution, which became evident later in the interview.

When asked what she would say about where the animals come from she said ‘evolution’ and that they are ‘just here’, adding that this relates to a person’s basic values of belief in science versus religion. However, she described the graphic as a representation of the scientific view of where things come from, which she said was important, and was expected in a science museum. She selected *mostly disagree* with evolution as an explanation for the origins of both vertebrate groups (birds and humans)—the only participant to do so—and *mostly agree* for the invertebrate group (insects).

Carol performed well on the questionnaire (top score of 11 out of 12), was the only participant that reported a graduate degree in biology, and described her knowledge of evolution as *some*. Her explanation for how change occurs was environmental changes, and was needs-based—e.g. it ‘had to’ occur and was the result of meeting ‘natural needs’ such as differences in physical structures for living in water or on land. The only reference to separation or divergence was in connection with the left and right branches at the bottom node. The two whales, *Balaenoptera musculus* and *Tursiops truncatus*, she described as having ‘evolved from’ the same ancestor, while the *Elomeryx* ‘became’ a hippo. She also thought that there were probably more animals that existed between the Artiodactyl ancestor and *Elomeryx* that were not shown on the graphic, similar to the number of extant taxa seen along the right branch.

Camilla (aged 35); Participant 006 – branched tree

Camilla is a White Hispanic/Latino female, aged 35, with a graduate degree in the humanities. Camilla has a background in museums both in terms of education and employment, and is a frequent visitor to museums. She conveyed a clear support of evolution, using the terms ancestors, related, common ancestors, evolved and time as well as agreeing with evolution for an origins explanation of insects, humans and birds. Common themes that emerged during her interview were how different the extant terminal taxa (hippo, baleen whales, toothed whales) are from each other, what scientists know and the potential significance of the absence of taxa on left branch—something that was noted by other participants. Although Camilla was comfortable answering questions, she commented later that it felt like being in school and taking a test.

Camilla talked about the depiction of extant whales as showing how they are related and thought that it might be illustrating that all whales have *Dorudon* as a common ancestor, and the overall graphic was showing that hippos and whales had a common ancestor (Artiodactyl ancestor) and when things diverged. In general, her emphasis was on how the three extant taxa are related in the graphic, specifically noting that they represent separate entities that diverged from the common ancestor. She used environmental explanations for how change happens, referred to speciation, and used needs-based reasoning; although no other mechanism or process was described beyond animals adapted to different environments. Other common themes were how different extant terminal taxa are from the Artiodactyl ancestor and each other (i.e. how much change had occurred between 55 million years ago and today), what scientists know and what the absence of taxa on the left branch might signify, which upon reflection she decided probably meant that little change had occurred rather than missing information.

Melissa (aged 17); Participant 007 – branched tree

Melissa is a White non-Hispanic/Latina female, aged 17, in grade 11. Melissa seemed relaxed and confident, spoke quickly with little or no hesitation in her initial interview responses, with a few pauses, ums, etc. during later explanations. Her demeanor during the interview and questionnaire responses conveyed her support of evolutionary ideas by indicating that she knew *a lot* about evolution, and *agreed* with evolution as an explanation for the origins of birds and humans. She only *mostly agreed* for an evolutionary origin of insects. Agreeing to a lesser extent for an evolutionary origin of insects than for one or both of the vertebrate groups was seen in a couple of other participants.

Although confident in her knowledge of evolution and scoring nine out of twelve on the questionnaire, she did not use more informed reasoning during her explanations such as selection, inheritance, or other process/technical terms. She referred to ancestry indirectly using the phrases ‘can be traced back to’ and ‘all come from the same creature’, and at times appeared to use ‘connected’ in lieu of ‘related’. She described what the graphic was trying to show with regards to *Elomeryx* and *Hippopotamus* in several ways—*Elomeryx* ‘becoming’ the *Hippopotamus*, as ‘kinda related’ or more closely related to each other than to the other animals, and ‘connected’. Extant whale taxa were described as having ‘evolved from’ a creature that had legs or webbed feet and as being closely related. The language variation suggests that a distinction is made between the depiction of two extant taxa (whales) as being ‘related’ and taxa at different end points (*Elomeryx* and *Hippopotamus amphibius*) as ‘connected’.

Mary (aged 41); Participant 008 – linear tree

Mary is a White non-Hispanic/Latina female, aged 41, with a graduate degree in social sciences. Mary seemed relaxed during the interview, reported a few visits to museums each year, *agreed* with evolution as an explanation for all groups in the questionnaire (insects, birds, humans), felt that it was *very important* for both scientists and her to know about evolution, and that she knew *quite a bit* about evolution.

During the interview she referred to ancestor, evolution and occasionally time, and used terms associated with more informed reasoning such as natural selection and adaptation. In addition, she referenced the environment and characteristics related to survival and reproduction depending on the environment, but also used needs-based reasoning (e.g. taxa needed to adapt).

She described the graphic as a kind of family tree, thought it was showing that whales are related and had evolved separately from the same ancestor, identified as *Dorudon*—but interpreted the linear depiction of taxa on the left branch as showing that *Elomeryx* was the ancestor of hippo. As with many other participants, she specifically noted the amount of change on the left of the graphic from Artiodactyl ancestor or *Elomeryx* to hippo, and absence of taxa on the left branch.

Ann (aged 11); Participant 009 – branched tree

Ann is a White female aged 11, in grade six. She was unsure of what to select for ethnicity on the questionnaire and after a brief discussion about how she thinks of herself or family conversations, she decided to put 'don't know' as I had explained that this was an option. Ann seemed a little hesitant on most answers, possibly nervous or lacking in confidence, and responded 'I don't know' when asked about how she thought changes might happen. Ann is a frequent visitor to museums reporting 20+ each year, *mostly agreed* with evolution as an explanation for the origins of all three groups, and felt she knew *a little* about evolution.

Ann talked about things 'evolving from others'—i.e. this specific taxon evolved from that named taxon—but appeared to view them as separate entities rather than a continuum. For example, when talking about how they evolved she traced the branches including nodes between each taxa, described a split having occurred for baleen and toothed whales, and that one lineage 'gets off' for *Elomeryx* and *Hippopotamus*. Furthermore, she referred to 'this' and 'this one' while pointing at the *Elomeryx* node when talking about how the *Hippopotamus* lineage started to evolve, as well as individual taxa on the right side of the graphic, which supports the interpretation that Ann viewed all terminal taxa as separate evolving entities, although she was unclear about the details and the process.

In general, Ann's responses are indicative of a dual or mixed view of evolution as anagenic and cladogenic—elements of her explanations referred to a named taxa as ancestral to another, while other responses indicated that she consider them to be separate from the descendant branch/lineage, and uses 'evolved from' more often than 'related'. Overall, she appeared to acknowledge and accept the idea that significant change can occur, even though she struggled with a mechanism for how that happens. Later, Ann said that she thought change was connected to organisms living in different places and the environment in the context of water versus land (i.e. aquatic versus terrestrial), including organisms' travelling to and exploring different places that 'they got used to'.

Andy (aged 12); Participant 010 – linear tree

Andy is a White non-Hispanic/Latino male, aged 12, in the seventh grade. He is the child of Samantha who also participated in the study (participant 011). Overall Andy seemed comfortable answering questions during the interview, but engaged in little conversation otherwise. Both Andy and his mother rarely interacted physically with the graphic by pointing or other gestures. Andy felt he knew *quite a bit* about evolution, *mostly agreed* with evolution as an explanation for the origins of insects and birds, and *agree* for human origins.

He talked about baleen and toothed whales as being in the same family, not the same species, more like cousins—and *Elomeryx* as developing over time and 'becoming' amphibious like a hippo. Overall, he said that half of the animals (Artiodactyl ancestor) 'evolved into' *Elomeryx* and the other half 'evolved into' whale-like things referring to the extinct taxa along the right branch but not the terminal whale taxa. Andy described adaptation to the environment and predators for how change happened, but did not mention any more informed principles of variation, inheritance and selection, and thought that taxa ‘had to’ evolve in relation to the food they eat, etc..

Samantha (aged 53); Participant 011 – branched tree

Samantha is a White non-Hispanic/Latina female, aged 53, with an undergraduate degree in the humanities. She participated in the study along with her child Andy (participant 010). She *agreed* with evolution as an origins explanation for all three groups, felt that it was *very important* for her and scientists to know about evolution, indicated her knowledge of evolution as *some*, and two visits to museums each year.

Samantha performed quite well on the questionnaire, achieving the second highest score of ten out of twelve correct responses. She gave environmental explanations for ‘how’ questions—talking about survival and reproduction, and used needs-based reasoning—e.g. how the Artiodactyl ‘needed to’ and ‘evolved to’ continue to survive and procreate. She described both the baleen and toothed whales, and *Elomeryx* and hippo, as being related (both branched depictions); although, when talking about what the graphic shows more generally—i.e. Artiodactyl ancestor and extant taxa—she used phrases such as ‘became’, ‘ultimately become’ and ‘evolved into’.

Lucy (aged 14); Participant 012 – linear tree

Lucy is a White non-Hispanic/Latina female, aged 14, in grade 9. Lucy and one of her parents participated in the study (Sarah, participant 013). Lucy *agreed* with evolution as an explanatory framework for insects, birds and human origins, and thought it was *pretty important* for scientists as well as her to know about evolution. She indicated her knowledge of evolution as *some*, and following the interview mentioned that they had recently learned about this at school, but was unsure whether this meant she would have performed well (she answered five of twelve questions correctly on the questionnaire).

Overall Lucy talked about things being ‘related’ by a common ancestor and described splits and separation for the branched parts of the graphic (bottom node and whales), used ‘evolved from’ for *Elomeryx* and *Hippopotamus amphibius*, and ‘evolved into’ when talking more generally about what was shown in the graphic. She discussed different geographic areas and climate as factors for how change happened, referred to natural selection and isolation of different ‘parts of the ancestor’, which suggests that she sees the ancestor as a population rather than an individual. She described taxa as ‘needing’ different traits to survive in different environments, but did not refer to differential survival or inheritance of traits.

Sarah (aged 47); Participant 013 – linear tree

Sarah is a White non-Hispanic/Latina female, aged 47 with a graduate degree in the humanities. Sarah’s responses to part C of the questionnaire were the same as Lucy, selecting *agree* with evolution as an explanation for origins and having *some* knowledge about the topic; however, Sarah indicated that she thought that it was more important (*very important*) for scientists and her to about evolution.

Sarah described the two extant whales as splitting at *Dorudon* 35 million years ago—which she later identified as their common ancestor—and said that they shared *Rodhocetus* and other taxa depicted along the right branch back to the Artiodactyl ancestor, which represented a branching off point that occurred 55 million years ago. *Elomeryx* was seen as the direct ancestor of *Hippopotamus amphibius*. She did not provide examples or an explanation about a mechanism or process for how change happened, and described it as occurring ‘through evolution’.

Alexa (aged 37); Participant 014 – branched tree

Alexa is a White non-Hispanic/Latina female, aged 37, with a graduate degree in social sciences. Alexa seemed comfortable during the interview session and expressed an interest in the study given her education background. She conveyed her support of evolution on the questionnaire, selecting *agree* for evolution as an explanation for the origins of all three groups and that it was *important* for her and scientists to know about—as well as expressing approval of my interest in communicating about evolution.

In her interview responses, Alexa referred to common ancestors and taxa being related for the bottom node and the right branch, along with noting a split between baleen and toothed whales. For 'how' change occurs, she referred to time and environmental factors, as well as the necessary physical adjustments and needing different parts in connection with these factors. Of particular interest, Alexa provided a more anagenic linear explanation—i.e. transformation of one taxon into another or evolution within a lineage—for what the graphic was trying to show about *Hippopotamus amphibius* and *Elomeryx* when using a branched tree, mirroring responses by participants who used the linear version of the tree.

Importantly however, she expressed uncertainty and confusion about the mismatch between its non-linear depiction and her thinking about these taxa before saying the *Hippopotamus amphibius* somehow 'evolved from' the *Elomeryx*. She noted that the branch was not a straight line, which is what she would expect to see if they had an ancestor-descendant relationship—ultimately thinking that it probably meant or was trying to show that they both evolved from the Artiodactyl and then split into two different groups from the shared node; in other words, a cladogenic explanation.

Despite this revision in her initial interpretation, her responses to questionnaire items suggest that she reverted to a more intuitive anagenic reasoning to answer these questions. For example, she was one of only two participants using a branched tree who answered question 1 about common ancestry incorrectly. Alexa's explanation, reflection on the significance of a branching depiction in the graphic and her subsequent reconsideration of its meaning supports the idea that the interpretation of relationships and change as anagenic or cladogenic is influenced by graphic depiction, and that a branched design supports a more accurate interpretation and explanation.

Ellie (aged 16); Participant 015 – branched tree

Ellie is a White, Asian Hispanic/Latina female, aged 16, in grade 11. Ellie was confident in her interview answers, responding quickly with little hesitation during the interview and answering the first two pages of the questionnaire (Part A), which involve interpreting the tree graphic, in a noticeably quicker time than most participants. She reported her annual museum visits as more than thirty, and indicated that it was *very important* for her and scientists to know about evolution and *agreed* with all three origins questions.

She used the word evolution and its variations, referred to ancestors as well as time. For 'how' explanations, she talked about the various things that can happen in the environment such as natural disasters, the Earth's rotation and even events that occur in space; although, when asked more specifically about 'how' that change happens, she referred to needs. Ellie described the taxa on both sides of the graphic as evolving from 'groups' with *Balaenoptera musculus* and *Tursiops truncatus* (baleen and toothed whales) as separate and distinct from *Dorudon*, which in turn are separate and distinct from their ancestor—i.e. there were subgroups that resulted in—or in her words 'created'—the two extant whales and *Dorudon*. In addition, she said that taxa on the left of the graphic originated from the same 'subgroup' (Artiodactyl ancestor), and that *Elomeryx* and *Hippopotamus amphibius* came from the same subgroup that she identified as the node.

Elliot (aged 11); Participant 016 – branched tree

Elliot is a White non-Hispanic/Latina female, aged 11, in the fifth grade. Elliot was outgoing and confident in her answers, *agreed* with evolution for all three origins questions, and indicated on the questionnaire that she knows *a lot* about evolution, although she only answered two questions correctly on the questionnaire. Also seen with another young participant, she was uncertain about how to answer the Hispanic/Latino question on the questionnaire, and after a brief conversation in which I provided the option of putting 'don't know', opted to select *not Hispanic/Latino*.

Elliot used a variety of terms to describe what was being shown in the graphic including 'related' and 'relationship', 'merged into' and 'how they were made'. Similar to other participants in the youngest age group (11-13), Elliot struggled with questions about 'how' change happens, often responding that she did not know; although later in the interview she indicated that environments changed, animals 'had to adapt' to different things, and that this process continued over generations.

Regarding what the graphic was trying to show about baleen and toothed whales, Elliot said it showed ancestors, and how they 'used to be' and what they 'used to have'—and about *Elomeryx* and *Hippopotamus amphibius*, that *Elomeryx* was a version before 'it [Artiodactyl ancestor] came to the hippo'. Overall, she referred to ancestors as earlier 'versions' or 'stages' of later, thought that change kept happening until you had 'something different', and viewed nodes as significant events or other points/markers of change. However, some elements of her explanations indicated that she did not necessarily view change from a straightforward developmental perspective—e.g. she referred to the creation of two new species from the Artiodactyl ancestor (*Elomeryx* and *Pakicetus*), described change as happening over multiple generations and millions of years, and talked about *Elomeryx* as both an 'earlier stage' of hippo, but also as 'related' based on physical characteristics.

Michael (aged 11); Participant 017 – linear tree

Michael is a White Non-Hispanic/Latino male, aged 11, in the fifth grade. Michael made little eye contact during the interview and interacted little with the graphic. He *agreed* with evolution as an explanation for human origins, but only *mostly agreed* for birds and *mostly disagreed* for insects. He was the only participant to *disagree* with evolution as an explanation for insect origins, but two other participants agreed more for one or both vertebrate groups than for insects—007 selected *agree* for birds and humans, *mostly agree* for insects; 010 selected *agree* for humans, *mostly agree* for birds and insects. He reported his knowledge of evolution and *some*, thought it was *very important* for him to know about the topic and *pretty important* for scientists.

Michael talked about a split and division in the context of the overall tree and extant whales, and described *Elomeryx* as the ancestor of hippos. He referred to the environment as a factor in evolutionary change and used needs-based reasoning; although he did not use the word 'need', but rather indicated that animals 'had to' evolve features to help them in the environment. He was the only participant to talk about animals choosing to move into different environment, but that there could have been a natural disaster. A few other participants (001, 005, 009) talked about organisms moving into other environments as a source of environmental change as opposed to the idea that the environment the organisms were in changed, but did not indicate that it was based on organismal choice.

Michael spent almost 20 minutes completing the questionnaire, with close to three quarters of that time on the first two pages, and his score was relatively low with three out of twelve correct responses. The patterns of responses were similar to other participants such as incorrectly answering question 1 as a linear tree user, and selecting the closest ancestor/common ancestors rather than descendant for character questions.

Josh (aged 18); Participant 018 – linear tree

Josh is a White non-Hispanic/Latino male, aged 18, in the twelfth grade. He is the older sibling of Daniel (participant 019) and Abby (participant 020). He seemed comfortable participating in the interview, and expressed an interest in graphic/visual design. Josh *agreed* with evolution as an explanation for all taxa, thought evolution was *very important* for both him to know about and scientists to study; he reported his knowledge of evolution as *quite a bit*.

Josh's explanations varied considerably during the interview, using 'evolved into' for *Elomeryx* and hippo, 'related' for whales, and 'evolved into' as well as referring to branching/splitting events for the tree overall (e.g. Artiodactyl ancestor and terminal taxa). Later he described how the tree could be used to explain how evolution works with the example (when asked) of the idea that humans 'directly evolved from' monkeys as an inaccurate way of thinking about these evolutionary relationships, despite having used similar ideas in his earlier explanations. Josh referred to location in the world, and different directions (which he said included the environment when asked) when asked about change within the context of 'what that called for from them to stay alive', i.e. needs-based reasoning.

He referenced change happening slowly over time, but otherwise did not refer to more informed principles such as variation and selection. In terms of the questionnaire, unlike many other participants Josh correctly included descendant taxa in several responses (see questions 6 and 12), but in keeping with most other linear tree users did not correctly identify *Elomeryx* and hippo as being most closely related among a set of options (see question 1).

Daniel (aged 15); Participant 019 – branched tree

Daniel is a White non-Hispanic/Latino male, aged 15, in the ninth grade. He is the younger sibling of Josh (participant 018) and older sibling of Abby (participant 020). He seemed comfortable during the interview, and was interested to know more about the study later. Daniel *agreed* with evolution as an explanation for all taxa, thought evolution was *very important* for scientists to study and for him to know about; he reported his knowledge of evolution as a range between *quite a bit* and *a lot*.

Daniel's explanations suggest mixed reasoning in terms of graphic interpretation and descriptions of evolutionary change, similar to what was seen with his older sibling (018). He used 'becomes' and 'turns into' when describing the tree overall, as well as 'comes from' and referring to branching events. When specifically asked about baleen and toothed whales, and *Elomeryx* and *Hippopotamus amphibius*, he said they were 'related' and 'came from' the same family. Daniel was the only participant to use the term 'want' as part of his explanations— "…if it [Artiodactyl ancestor] wants to gets more food it can turn more into like an aquatic animal.", and described later that they learn to swim more and develop in a way that made it easier to get food. He also said developing/getting features help them survive because 'only the best fit – won't die off', and mentioned natural selection twice as well as geographic isolation. In terms of the questionnaire, he correctly included descendants for questions 6 and 12 that most other participants missed, as did his older sibling (018).

Abby (aged 13); Participant 020 – branched tree

Abby is a White non-Hispanic/Latina female, aged 13, in the seventh grade. She is a younger sibling of both Josh (participant 018) and Daniel (participant 019). Abby spoke quietly during the interview, and seemed more hesitant in her responses (e.g. long pauses). She *agreed* with evolution as an explanation for the origins of all three groups (insects, birds, humans); although an erased mark on the questionnaire indicates that her initial answer for insects might have been *mostly agree*, but it is unknown whether this mark was intentional (as noted earlier, two participant agreed to a lesser extent for an evolutionary origins of insects than the other taxa). Abby thought evolution was *very important* for her to know about and for scientist to study. Similar to her sibling Daniel (019), she selected a range for her response to how much she knew about evolution of between *some* and *quite a bit*.

Abby's explanations, as was seen with her two siblings, was mixed with regards to the language used. She used 'turned into', 'became' and 'evolved into' when describing the tree overall and for a 'how' question, but also referred to how it 'splits off' and 'branches off'. When asked specifically about taxa—baleen and toothed whales, *Elomeryx* and hippo—she used 'evolved from'. Abby's explanation of the ancestor of the hippo changed during the interview. She initially described *Elomeryx* as the ancestor of the hippo and indicated a connection between the Artiodactyl ancestor and *Elomeryx*, but later said that the Artiodactyl ancestor is the ancestor of the *Elomeryx*/hippo node and that both taxa branch off of that. She was unsure what the nodes were or were trying to show, but thought they could represent time.

Abby referred to the environment in response to 'how' explanations, but not provide any detail, and her only reference to more informed VIST principles (variation, inheritance, selection and time) was that change occurred slowly over time. In terms of questionnaire performance, she was one of only two participants to correctly answer question 4—identify that *Dorudon* is more closely related to *Tursiops truncatus* than *Rodhocetus*—and as was seen with most branched tree users correctly identified *Elomeryx* and *Hippopotamus amphibius* as being the most closely related among a set of options (question 1).

Appendix E. Participant Interview Transcripts

Transcripts follow a denaturalized format—participant verbal responses are transcribed verbatim and include short pauses, disjointed points in sentences, emphasis, actions (e.g. laughter), and any paralanguage (e.g. um, er, well). Notes: Transcript does not include dialogue related to orientation or organizational related items including a summary of what the interview is going to involve and naming the animals; dashes are used to indicate short pauses (1 second or less) and [pause] for longer pauses.

Megan (aged 11); Participant 001 – linear tree

Date: 01/30/2014 Participant #: 001_01302014_1_L Duration: 3 minutes

I = interviewer; P= participant

I: What do you think this picture is trying to show?

P: I think it's trying to show that a long time ago there is – there is the animal at the bottom [POINT at Artiodactyl ancestor] – and then it slowly changed into all these [TRACE left branch, then right branch from bottom to top].

I: How do you think that happened?

P: Well, from evolving from different needs. Like – if like – if, if in certain habitats it needs to be able to swim or it needs to able to reach up higher or something like that it will develop body parts that enable it to do that.

I: What kinds of things do you see in this graphic?

P: I see a chart [TRACE along timeline from top to bottom], I see paths [TRACE part of left branch up], and I see the animals and their names [GESTURE generally at taxa].

I: What do you think this picture is trying to show you about *Balaenoptera musculus* and *Tursiops truncatus* [POINT to taxa]?

P: That they both evolved from the same creature [POINT at *Dorudon*] but they are two different things [POINT at *Balaenoptera*, then *Tursiops*].

I: What do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa]?

P: That the *Elomeryx* eventually became the *Hippopotamus*?

I: At one time there was one species of animal [POINT to Artiodactyl ancestor] and now there are hippopotamuses, baleen whales and toothed whales [POINT to taxa]? How do you explain that?

P: Well, after there are so many – it – maybe they spread out to different habitats and then different habitats, they require – they require different things.

I: Is there anything else that you think it is interesting about this graphic?

P: I think it is interesting that in the end all of them are different [GESTURE across terminal taxa from left to right], like that.

I: OK – so all of the ones shown at the top here are different [POINT to taxa across top, left to right]. How do think they are different – different from each other [GESTURE at terminal taxa across top] or different from some of the other animals on here [GESTURE at non-terminal taxa]?

P: I would say different from each other cause the hippopotamus had legs [GESTURE to taxa], and this is really, really big [COMPARE use thumb and index to measure *Balaenoptera*], bigger than the hippopotamus [COMPARE use thumb and index to measure *Hippopotamus*]. This is small [COMPARE use thumb and index to measure *Tursiops*], but some of them are the same size as the hippopotamus [COMPARE use thumb and index to measure *Hippopotamus*] – it's like some of them grew a bunch

[GESTURE with both hands to indicate small (close) to big (further apart)], and this guy looks like he shrunk from its ancestor [surprise] [COMPARE use thumb and index to measure *Tursiops*, then TRACE to *Dorudon*] – and I just think it's a lot.

I: If you had to tell someone about this diagram or this graphic, what would you tell them?

P: I would say along the side here [POINT along time marks], um – this shows, this shows how many years ago and the animals along this line or by this line [TRACE from *Elomeryx* to *Dorudon*] or on the line or close to the line [POINT to branch segment above *Elomeryx*] – it – they, they lived around those years – around that time period. And I'd say that these are the animals [POINT at *Pakicetus*, *Rodhocetus*, *Dorudon*] that are – that, that the animals here, their names are above them or by them [POINT at *Hippopotamus*, *Balaenoptera*, *Tursiops*], and that they are all evolving from this guy [POINT at Artiodactyl ancestor].

I: Thank you very much.

Peter (aged 16); Participant 002 – linear tree

Date: 02/08/2014 Participant #: 002_02082014_2_L Duration: 4 minutes, 5 seconds

I = interviewer; P= participant

I: What do you think this picture is trying to show?

P: Um – it looks like an evolutionary tree. It looks like we have the [pause] common ancestor – I guess – down there [GESTURE at Artiodactyl ancestor] and showing a relationship between that family of whales and hippopotamus [GESTURE with open hand upward].

I: How do you think that happened?

P: Um – well – so – we had – I guess there was this ancestor there [POINT at Artiodactyl ancestor] – the common ancestor – and – you know, the one group that became the hippopota – hippopotami – I don't know if that is the plural for it [I: it is; P: OK, thank you] and yet they were in the species, the one species kinda got separated. And then there are different stimuli, different mutations that – um – occur – and, over time the mutations that fit the different stimuli become so great that you know you can't call it the same species anymore. You know this is happening over millions of year [GESTURE with open hand upward] – so this keeps happening – and you have, you know hippopotamus [GESTURE with open hand upward] and – a whale [GESTURE with open hand upward].

I: What kinds of things do you see here?

P: Um – I see – well, there, there is a change, I guess, in the physical shape. Uh – you can the, how, you know, the – artiodactyl [POINT] becomes the baleen whale – you have – the, um – species in between – that [pause] – that sh, that show the differences their forming and um, how its becoming the whale.

I: What do you think this picture is trying to show you about *Balaenoptera musculus* and *Tursiops truncatus* [POINT to taxa]?

P: Um, I, I guess it would be showing – that – not only are the two related, but that they are related to a hippopotamus.

I: What do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa]?

P: Um – I think it would be showing that – uh, the *Hippopotamus amphibius*, um, once was a type of *Elomeryx*, but then [snaps fingers] something happening. And I guess with my understanding of evolution, you know, there would be – a mutation that occurred and would split off and maybe the *Elomeryx* was wasn't so suited for survival anymore and went, went, uh, onto become extinct, but the *hippopotamus* was so it is still alive.

I: OK, so you think that *Elomeryx* separated and split off from the hippopotamus?

P: Mm-hmm.

I: At one time there was one species of animal [POINT to Artiodactyl ancestor] and now there are hippopotamuses, baleen whales and toothed whales [POINT to taxa]? How do you explain that?

P: Um – the, the common ancestor was living in a certain time and something changed or a mutation occurred – and – and probably, probably both of those of those things happened – and the mutation made that select group or that individual more suited so that mutation, you know, developed and – kept, kept happening and so – ah, after a while, you know, they would split off and become two different species [rising pitch].

I: Is there anything else that you think it is interesting about this graphic?

P: [pauses] Um – I guess not anything that we haven't talked about before, so [pause] no.

I: OK. If you had to tell someone about this diagram or this graphic, what would you tell them?

P: I would tell them that, uh, hippopotami and – uh, baleen whales and toothed whales are – um, dist – hmm, maybe not distantly compared to other animals – but, distantly, um, related by the artiodactyl ancestor. I wouldn't say the artiodactyl ancestor – I would just say a common ancestor.

I: OK – anything else you want to tell me about this graphic?

P: Um – no.

I: Great. Thank you very much.

Thomas (aged 45); Participant 003 – linear tree

Date: 02/08/2014 Participant #: 003_02082014_3_L Duration: 7 minutes, 25 seconds

I = interviewer; P= participant

I: What do you think this picture is trying to show?

P: Um – looks like we are looking back for common ancestor. Like once upon a time, these three were all related [POINT at hippo, baleen whale and toothed whale]. This is its great grandparent [GESTURE down right side branch; POINT at Artiodactyl ancestor], but they have branched off [GESTURE with hand up right branch].

I: How do you think that happened?

P: [pause] My personal feelings? [pause] Ah.

I: Yeah, your particular opinion on that.

P: They evolve – evolved. Natural selection [pause] Uh, lots of – lots of things were tried and didn't work out, and over the span of generations those were eliminated from the gene pool. But for whatever – whatever was the case – in the natural environment these found a spot and could flourish [GESTURE with hand at *Elomeryx* area, and then moved side to side and up], and then their babies could flourish, and then their babies could flourish, and then just eventually [GESTURE up around top of graphic, fingers spread] over millions of generations they start looking a little bit different. Some of them swim [GESTURE at baleen and toothed whales], and some of them don't [GESTURE at hippo] – or not as much.

I: What kinds of things do you see on this graphic?

P: [pause] Well – if we look at the right side. I can see – it's easier for me to see the continuity. This [POINT at *Pakicetus*] to this [POINT at *Rodhocetus*] to this [POINT at

Dorudon] to those [SPLIT between two baleen and toothed whales with two fingers]. And, I do see continuity here as well [POINT at Artiodactyl ancestor with right finger, then at *Elomeryx*, then at hippo; then TRACE from hippo to artiodactyl ancestor]. Um [pause] My [pause] the question I would have is – is – they're really different [laughs] [POINT at hippo with left finger, baleen and toothed with right finger and move back and forth between whales] – how did that happen [TRACE down left side with left finger, and right side with right finger]. And so right here [POINT at branch split just above Artiodactyl ancestor] – and of course the further back you go, the more murkier it is for scientists. But – I guess they look quite a bit similar [POINT at *Elomeryx* with left finger, and at *Pakicetus* with right finger]. Uh, it's just where did that first initial division occur [TRACE from *Elomeryx* to Artiodactyl with left finger, and from *Pakicetus* to ancestor with right finger – back and forth three times]. But, I think it looks great actually.

I: What do you think this picture is trying to show about *Balaenoptera musculus* and *Tursiops truncatus* [POINT to taxa]?

P: That they are more closely related. Uh, and it looks the – they have become distinct species [GESTURE towards top of graphic] 35 million years ago and not 55 million years ago – so they are more closely related. [pause] That might be my cousin, not my cousin eight times removed or.

I: What do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa]?

P: Well – it seems like the hippopotamus is a dir, direct descendant of – the – *Elomeryx*. Whereas, these two had a common ancestor [SPLIT with two fingers on right hand between baleen and toothed whales] in this [TRACE with two fingers down branch to

Dorudon] – it looks like this is a direct line [TRACE with left hand finger from *Elomeryx* to hippo, to *Elomeryx*, to hippo].

I: At one time there was one species of animal [POINT to Artiodactyl ancestor] and now there are hippopotamuses, baleen whales and toothed whales [POINT to taxa]? How do you explain this?

P: Uh. Well – the process of natural selection. Uh – an animal has lots of babies and if they thrive – they are rewarded by getting, they are able to live and then they make babies and if they don't thrive – they perish. And that enough generations go by [GESTURE rolling hand movement with right hand] – that, gene pool, uh, is done – it, it becomes extinct, um, or it dies out. And it might be a subtle as a, a trait [GESTURE up and down at a point in mid-air with fingers on right hand] from generation to generation [GESTURE rolling hand movement with right hand] – you get enough generations and, uh, and then the traits can become much more distinct [pause] I think.

I: Is there anything else that you think it is interesting about this graphic?

P: [pause] Well – um – I don't know if this is interesting or not. Uh, is uh – are these animals all to scale? Um, blue whales tend to be pret-ty big, and that might be helpful if they were to scale. Um – I – are these to scale [emphasis] [POINT to today line and then 36 million years ago line]? Like if this is 36 million years [COMPARE with right finger and thumb space between today and 36 million years] – if this were 72 million years [COMPARE with right finger and thumb space between 36 and 47.5 million years, and then between 47.5 and 48.5 million years] next with that might be helpful or this were to stretched out [GESTURE to indicate an expansion with left hand moving up and right hand moving down].

I: So if the both animals as well as the time were to scale? [talking at same time]

P: The time were to scale. [talking at same time] Hm-hmm. [talking at the same time]

P: I do think that, you know, we read – we in the non science, non mathematic, uh, areas [GESTURE outward with right hand] – we read these numbers and we're just – we don't really get how long ago 55 million years or what is four hundred billions stars in the galaxy. What – that, that number is so.

I: That those numbers are challenging and if you don't work – specialize in it. [talking at same time]

P: That there so [laughs]. [talking at same time]

P: I mean. Yeah, I go to the store and buy a dozen apples. These, these numbers are just so huge [GESTURE outward and upward with right hand] that we really don't, uh. So for me, you know, I can stop looking at the word million [POINT at 36 million years line and then at 47.5 million year line] and just see well that is 36 [COMPARE with right finger and thumb the space between today and 36 million] and that should be 72 [COMPARE use previous space made with right finger and thumb to show equivalent space below the 36 million year line], and that would, you know [COMPARE use previous space made with finger and thumb to show equivalent space to show equivalent space below from previous point below 36 million years] – but [pause] it looks pretty clear.

I: My last question is, if you had to tell someone about this diagram or this graphic, what would you tell them?

P: Um, that – it [pause] pretty – clearly – shows – uh – common ancestry. That, that it shows what scientists have uncovered or they've hypothesized or they believe. That this is – if you go back enough generations – this is – uh – this is – how it was. X is a direct descendant of Y and Y is the direct descendant [GESTURE with right hand towards right side of graphic] and. [trails off]

I: In terms of particular taxon here are direct descendants of others [GESTURE with right hand generally at graphic].

P: Hm-mmm. Yes, that this [POINT with right hand finger at *Rodhocetus*] is a direct descendant of [POINT right hand finger *Pakicetus*] and that this [POINT right hand finger *Dorudon*] is the direct descendant of this [POINT right hand finger *Rodhocetus*]. And then of this [POINT right hand finger at *Pakicetus* with left hand on bottom of right arm] – and of this as well [POINT right hand finger at Artiodactyl ancestor while left hand is on bottom of right arm] – I mean. I guess another question that I would have is are there any other – in addition to these three [POINT left hand finger at hippo, then baleen then toothed] – was there something that split here? [POINT with left hand finger at 48.5 million year ago level] Something that split there? [POINT with left hand finger at branch location of *Rodhocetus*] Uh, this doesn't – say – yes, it, there are – it doesn't say no there's not. It just says for these three current animals [POINT right hand finger hippo, then baleen, then toothed and back and forth several times], you know – is a, a hammerhead shark [POINT with right hand finger at baleen whale] – not a shark – are, are there different whales, porpoises dolphins [POINT with right hand finger baleen whale and then toothed whale]. Are, are there any other animals [POINT with right thumb and finger at toothed whale]. But, I think it looks great.

I: That is all the questions I have – we are going to move onto the questionnaire.

Judy (aged 42): Participant 004 – branched tree

Date: 02/08/2014 Participant #: 004_02082014_3_BR Duration: 10 minutes, 19 seconds

I = interviewer; P= participant

I: What do you think this picture is trying to show?

P: Uh, it shows how – these present day animals [POINT with open left hand at hippo, then baleen whale, then toothed whale] – it shows present day animals [POINT with open left hand at whales] and the other animals it evolved from [GESTURE with open left hand towards right branch]. And it's kinda like a flow chart [TRACE with open left hand from bottom of graphic up left branch and then up right branch]. And they all evolved from this guy [POINT left hand finger at Artiodactyl ancestor].

I: And, how do you think that happened?

P: Oh, I think – the, the, the [long pause]

I: You said they all evolved [talking over each other] – How do you think they evolved from this guy? [talking at same time]

P: The chart happened? Yeah, OK. [talking at same time]

P: Well, I would assume from [GESTURE open left hand at graphic] – a very rudimentary understanding of evolution that [POINT open left hand toward Artiodactyl ancestor], that through procreation this animal continues to pass through the generations [GESTURE with open left hand towards artiodactyl ancestor and surrounding area] and adaptions happen due to accidents or environment, uh, other animals [GESTURE with open left hand downward in mid-air with each example] – and. Uh, so between here [POINT with left hand finger at Artiodactyl ancestor] and here [POINT with left hand finger at *Elomeryx*], there, it's not just [POINT with left hand finger at Artiodactyl ancestor] one day, overnight [POINT with left hand finger Artiodactyl ancestor], this happens, but there's lots of generations [TRACE follow along left branch from horizontal part of bottom branch to node] between here [POINT at *Elomeryx*/*Hippopotamus amphibius* node]. And then at some point [POINT at *Elomeryx*/hippo node continues] – I assuming that they've learned this by looking at the fossil record [POINT at node continues] and by DNA – there's been a split [POINT at *Elomeryx*/hippo node] and this guy [POINT at *Elomeryx*], who kinda looks like a – horse-dog sort of thing, uh, has that, that branch stopped evolving [TRACE from node up towards *Elomeryx*] and he has died out [POINT at *Elomeryx*] – and that this branch [TRACE from node up towards hippo], is this guy [POINT at hippo]. And the same thing has happened over here [POINT bottom node on right branch] – multiple generations [GESTURE generally a different points from bottom to top along right branch] doing their thing.

I: What kinds of things do you see here?

P: Well – um [pause] I see the flow chart [GESTURE with open left hand towards graphic], but the thing that interests me is that – I'm – this is something that I don't – I would like to know more about [POINT left hand finger toothed to baleen and back and forth several times] – so this is what interests me, is how dolphin and whales are related. So the thing that caught my eye right away are that this [POINT at toothed whale], what I would call a dolphin, is a toothed whale. Uh, I've never understood how these two are quite related [POINT back and forth between baleen and toothed whales]. So that would be something I would want to learn a little more about.

I: In terms of how we know that – or a little more about their hist, shared history?

P: Um, yeah – I would be interested to know how they split off [POINT at baleen and toothed node, then baleen and then toothed whales]. And how, um, scientists can tell the difference [POINT back and forth between toothed and baleen whales]. I think, I mean, I know right away what baleen is [POINT at baleen whale] – but, you know, there are whales that have teeth [POINT at baleen whale] – so, I mean, are they toothed whales [POINT toothed]? Or are – so I would want to know more about the whole shebang.

I: About everything.

P: Yeah.

I: What do you think this picture is trying to show about *Balaenoptera musculus* and *Tursiops truncatus* [POINT to taxa]?

P: Um, that they are related animals [POINT baleen then toothed]. That split off [POINT baleen and toothed node] from a single ancestor 35 million years ago. I also find it interesting that [POINT hippo] – we know these are mammals [POINT hippo, then baleen, then toothed] – but that it was – that these are so [POINT hippo, then baleen] – far [GESTURE both hands spread apart] related from each other that 55 million years ago [POINT bottom node] they would had, been – I mean that's a long time [GESTURE open left hand from bottom to top to bottom] for them to look so differently [GESTURE across terminal taxa from left to right].

I: What do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa]?

P: That they had a common ancestor [pause] [POINT Elomeryx and hippo node] I guess that would be like 45 million years ago or so [POINT to space above 47.5 million years ago]. And that this guy is extinct [POINT *Elomeryx*]. That this branch [LINE trace along branch from node to *Elomeryx*] from the common ancestor [POINT node, then *Elomeryx*, then node] is extinct. And that the hippopotamus [POINT hippo, then node, then hippo] is present day – the guy we see in zoos and what not. [pause] And I'm – guessing that maybe there's an animal here [POINT and draw circles around *Elomeryx* and hippo node] that maybe we haven't found any fossil record for so we don't have someone to name there [POINT node].

I: At one time there was one species of animal [POINT to Artiodactyl ancestor] and now there are hippopotamuses, baleen whales and toothed whales [POINT to taxa]? How do you explain that?

P: How do I?

I: Yeah, how do you [emphasis] explain this?

P: [pause] I feel like I'm repeating myself [laughs].

I: That's, that's perfectly fine.

P: That [POINT to Artiodactyl ancestor], they all [GESTURE at top of graphic] that all life had common ancestors – and that we go back to 55 million years ago [POINT with left hand pinky at bottom node] we can look at the common ancestor of the hippopotamus, the baleen whale and the toothed whale [POINT left hand finger at hippo, then baleen, then toothed]. And that – through evolution – environmental pressures, you know – predation [GESTURE open left hand generally gesturing, downward on each example] – things like that – accidents [GESTURE open left hand upward] – uh, we – this artiodactyl, ancestor [POINT at Artiodactyl ancestor] – he is, uh, split off at some point [POINT at *Pakicetus* node] and that this guy [POINT at *Pakicetus*] is extinct, *Pakicetus*, that *Rod* [POINT at *Rodhocetus* briefly] – and then further on *Rodhocetus* is extinct [POINT at *Pakicetus* node; then TRACE along branch to *Rodhocetus* node; then POINT at *Rodhocetus*]. I wouldn't say that [POINT along bottom branch by Artiodactyl ancestor] – it, like that it splits [GESTURE generally gestures as graphic around nodes and branches from bottom to top], but I wonder if maybe [pause] when, with this split [POINT at *Pakicetus* node, then *Pakicetus*, then along *Rodhocetus* node] it's that this continues to evolve [TRACE from *Pakicetus* node to *Rodhocetus* node]. So we can think of him [POINT at Artiodactyl ancestor] as, whatever he is [POINT at *Pakicetus* node], he evolves into this [POINT at *Pakicetus*] but then the other branch [TRACE from *Pakicetus* node to *Rodhocetus* node] continues evolving, evolves into that [POINT at *Rodhocetus*], and then continues evolving [TRACE from *Rodhocetus* node, then to *Dorudon*, then to baleen/toothed node].

I: And you think this branch [POINT to bottom part of right branch] is from here [POINT to bottom node]?

P: Yeah [POINT to bottom node and along branch].

I: OK.

P: So yeah. So. [pause] I don't know. [pause] Would that mean that *Pakicetus* is here [POINT at *Pakicetus* node] – but then his ancestors continued evolving [POINT at *Rodhocetus* node] – and then [GESTURE downwards towards that section of graphic] – ahhh [frustrated].

I: Well, what do you think?

P: I feel like I don't know enough information. And, I would – if I saw this, in a museum – I would stop and read the little [POINT to the top and right of graphic], the little hoo-ha that's with it [unclear].

I: OK, for a little bit of explanation. But you certainly think that this lineage [TRACE from *Pakicetus* node to *Rodhocetus* node] may be, related to either *Paki* – this one [GESTURE around *Pakicetus*], you mentioned *Pakicetus* being here and continuing [TRACE along bottom branch towards to *Pakicetus* node; then POINT at *Rodhocetus* node] – or, I think originally you were saying the artiodactyl continuing on [POINT at Artiodactyl ancestor; then TRACE along bottom branch to *Pakicetus* node, up to *Rodhocetus* node].

P: Well, I think the artiodactyl [POINT at Artiodactyl ancestor] as he evolves [TRACE along bottom branch to Pakicetus node] – he evolves into *Pakicetus* [POINT at *Pakicetus*]. And then [POINT at *Pakicetus* node] that – whatever ancestors [POINT at *Pakicetus* and then at *Pakicetus* node] adapted to the changing times [POINT at *Rodhocetus* node, then at *Pakicetus* node, then back to *Rodhocetus* node], and the predators and things – left *Pakicetus* behind [TRACE from *Pakicetus* along branch to *Rodhocetus* node]. So I don't think he looked like this [POINT at Artiodactyl ancestor] – you know – 52 million years ago [POINT at *Pakicetus* node]. I think that as he was evolving [GESTURE along branch from Artiodactyl ancestor to *Pakicetus*] this guy got left behind [POINT at *Pakicetus*] and he continued to evolve [POINT at *Pakicetus* node, then at *Rodhocetus* node, then at *Rodhocetus*, then at *Dorudon* node]. So he looked a lot like *Pakicetus* here [POINT at branch section between *Pakicetus* and *Rodhocetus* nodes].

I: But was different from.

P: Right.

I: OK.

P: So, he got, you know, orange hair or something [GESTURE at graphic around *Pakicetus* and *Rodhocetus* area] – and, and that was better [POINT at branch section between

Pakicetus and *Rodhocetus* nodes]. And then again, it happens again [POINT at *Rodhocetus* node, then at *Rodhocetus*, then at node] – where he looks a lot like *Rodhocetus*, but – this definite [POINT at *Rodhocetus*] animal that we're able to name cause he's different from everybody else [GESTURE around area of *Rodhocetus* and *Pakicetus*] continues evolving [TRACE from *Rodhocetus* node to *Dorudon* node], you know, because he has, you know, bigger teeth [POINT at branch section between *Rodhocetus* and *Dorudon*] and he – ends up being this guy [POINT at *Dorudon*]. And then this guy [POINT at *Dorudon*] gets left behind as – his – progeny [GESTURE at *Dorudon* node] evolve into these guys [GESTURE at baleen and toothed node, then at baleen and toothed whales].

I: Is there anything else that you think it is interesting about this graphic?

P: Um [pause] – you know, it doesn't surprise me that hippopotamus [POINT at hippo] is different from the whales [POINT at whales] – um [pause] you know, I would say – intuitively "Oh, a hippopotamus is different from whales", but I like the idea that [GESTURE open left hand outward in air several times] – it illustrates, yet again, that there's a common ancestor for all life on Earth. And that, that we [GESTURE open left hand to overall branch on left side, then top branch on right side, then back and forth and then generally at graphic] – that scientists have been able research to figure out where [POINT artiodactyl ancestor, then towards left side, and then right side of graphic] these guys branched off. [pause] I like that.

I: So, you like that – they look different, you think of them as being different – but that this graphic shows you that they're not that different?

P: Yeah – although, I – I mean, you know. I think – because I have a conventional understanding of time. I think that 55 million years ago is a long time. So [pause] you know [pause] they are different [pause] and it's taken 55 million years for them to look so different [GESTURE open left hand general gesture in air]. I think that's impressive.

I: So – it – they look different – but, there, it took a long time for that to happen?

P: Right.

I: If you had to tell someone about this diagram or this graphic, what would you tell them?

P: I, you know, I would probably have trouble remembering these different points [POINT at different timelines from top to bottom, and then general gesturing at timeline area]. I've never been good with remembering dates specifically, but that I – I would be able to walk away from this and say 55 [GESTURE generally at graphic] – there, that hippopotamus and whales – I probably wouldn't differentiate [POINT at baleen and toothed whales, then back and forth] – because these are all people we see [POINT at hippo, then baleen whale then toothed whale] – today. I would probably say hippopotamus, whales and dolphins [POINT at hippo, then baleen, then toothed] because I still don't understand how that works [laughs] evolved from a common ancestor 55 million years ago [GESTURE at Artiodactyl ancestor]. That would be the sentence that I [emphasis] would be able to repeat [GESTURE generally in the air].

I: And if I, I – for example brought someone in here and said – um, can you tell them about this graphic. So with it in front of you, what would you tell them?

P: I would probably use what I just said as a topic sentence.

I: Mm-hmm.

P: And then I would talk about how [GESTURE generally in the air] – I think I would probably bring in the fact – that 55 million years ago [GESTURE with both open hands at artiodactyl ancestor] their common ancestor [GESTURE with both open hands at hippo and whales] lived on land and had legs [GESTURE with open hands at Artiodactyl ancestor]. Although, I guess I can't really say they lived on land, but – I mean, he has legs [GESTURE at Artiodactyl ancestor]. And that, the, the hippopotamus line [GESTURE along branch on right side and generally on right side] branched from the dolphin line, the whale line, and one started returning and evolving towards living life in the sea animal [GESTURE upward along branch on right side] and the other continued to evolve as a land animal [GESTURE upward along branch on left side]. [pause] Sound good?

I: Yep, perfect. It's whatever you tell people.

I: So, that's all the questions I have.

Carol (aged 44); Participant 005 – linear tree

Date: 02/09/2014 Participant #: 005_02092014_3_L Duration: 6 minutes, 30 seconds

I = interviewer; P= participant

I: What do you think this picture is trying to show?

P: Uh – evolution? Of – different – animals, species.

I: How do you think that happened?

P: How do I think that happened? Um [pause] Well, over time the creatures adapted to their environment and they – change, um, their body shapes and – morphology according to their natural needs.

I: So, what kinds of things do you in this graphic?

P: What kinds of things?

I: Hm-hmm. What kinds of things do you see depicted here – or shown here?

I: Well – this is the animals at the top that's [TRACE from hippo to baleen whale to toothed whale, and then back], that we know of today – and, um – it goes back [TRACE with left hand finger from hippo down left branch to around 47.5 million year ago timeline, then back up and then back down] – in – time – of what it's cousins [TRACE down branch to 55 million years ago] [pause] and – [TRACE from top or right side of graphic to artiodactyl ancestor] um, until it all came down to this [emphasis] animal 55 million years ago [POINT at 55 million years ago text] as where everything originated [POINT at Artiodactyl ancestor] – from [GESTURE circular gestures around top middle and right of graphic], according to this picture? [cell phone beeps several times]

I: Now, what do you think this picture is trying to show about *Balaenoptera musculus* and *Tursiops truncatus* [POINT to taxa]?

P: Oh. Um. [pause] They came from the same genetic line [GESTURE with open left hand along right side of graphic]? [cell phone beeps, and checks cell phone]

I: So, you think it's trying to show they came from [GESTURE open hand along right side of graphic] – the same point or the same shared history?

P: Same shared history – yeah. Evolved from the same, um, ancestor [GESTURE with open hands general circular movement] so to speak.

I: And, what do you think this picture is trying to show you about *Hippopotamus amphibius* and *Elomeryx* [POINT to taxa]?

P: Oh. [pause] Like 36 million yeas ago there were no hippopotamus [POINT left hand finger at hippo] – it was just this *Elomeryx* [TRACE branch from hippo to *Elomeryx*; POINT at *Elomeryx*; then TRACE branch up to hippo] and – um – over 36 million years it became a hippo [GESTURE with open left hand upwards from *Elomeryx* to hippo] – huh [laughs].

I: Now, at one time there was one species of animal [POINT to Artiodactyl ancestor] and now there are hippopotamuses, baleen whales and toothed whales [POINT to taxa]? How would you explain that?

P: Oh. Huh. Yeah – good question [laughs] I don't know. [pause] Um – maybe [pause] the animals [pause] [GESTURE generally at graphic with left hand] um, kind of drifted away from each [GESTURE left and right hand together and moved apart from each other] and some started living in a drier environment, where the water kept, level kept going down and, and needed to have [GESTURE generally at graphic and in air with left hand and then both hands], um, land, um – physical structures like feet and lungs and to breathe. So – while the – other, the rest of the animals [GESTURE with open left hand at right side of graphic] stayed in the water and they kept their – structures? So that, one branch of that [GESTURE with open left hand at top left side of graphic] species went into land [GESTURE off top left of graphic] and – somehow it [GESTURE with open left hand down left side and up of left side of graphic], – yeah – it went to a different line. [pause] Whatever the environment became, you know, temperature drop or ice melting or [GESTURE with both hands in air] – whatever.

I: Is there anything else that you think it is interesting about this graphic?

P: Anything else interesting?

I: That maybe I haven't asked you about?

P: See there are no animals with these two timelines [POINT left hand finger to 48.5 and 47.5 million years ago time lines and move between them] so you wonder – I wonder what happened here [POINT to 48.5 and 47.5 million years ago timelines and move between them]. [pause] It didn't just go from one, animal [POINT at Artiodactyl ancestor] – and made into one animal [TRACE branch from Artiodactyl ancestor along branch to hippo, then back to *Elomeryx*; GESTURE clockwise circle around *Elomeryx*] and then become a hippo [POINT at hippo] – I bet there are a few other animals in between [POINT at several points along branch between Artiodactyl ancestor and *Elomeryx*] – like this branch [TRACE right branch from *Pakicetus* to baleen whale then back to *Pakicetus*] – but what happened there [GESTURE to open space on left side branch as before].

I: So you are wondering what happened and why there isn't anything shown there [GESTURE open right hand face down along section of left branch without taxa]?

P: Yes. Right. Right. [pause] Maybe they don't know – they just, you know – but then they could probably say, say something [POINT to section without taxa on left branch] to that line "we don't know what happened here, but we suspect this is what happened."

I: OK.

P: That would help, you know, audiences kind of – get a – more satisfactory answer in the head [GESTURE with open hands generally in the air].

I: Now, if you had to tell someone about this diagram or this graphic, what would you tell them?

P: What I tell them? Um – that – um. [pause] That it's, um – it's very interesting to know where we all came from [GESTURE with open hands generally in the air] – you know – originated from somewhere [GESTURE with open hands generally in the air] – and [pause] um, this is a picture of these animals [GESTURE at hippo, then baleen whale, then toothed whale and back to hippo], but you wanted to know more about other species [GESTURE with open hands generally in the air] and where they came from, like maybe, the human [laughs].

I: So that this is talking about one group, but it would, you want to know if they would be interested in more [GESTURE open hand generally at graphic].

I: And if I invited someone in here, and – I said "tell them what this graphic is all about" – what would you tell them. What is the sort of purpose or role of this graphic?

P: What is the role? Um. [pause] The purpose [GESTURE with left hand at graphic] is to the make the public understand [pause] um [pause] what [pause] where the where the animals come from [rising tone]. And [pause]

I: And if someone said, "where do they come from – what would you say?

P: I said. Um, where do they come from. They, from evolution. [GESTURE with open hands at graphic] [pause] They're just here [emphasis]. I mean [GESTURE with open hands generally in air], we [laughs], I can't [laughs]. I mean, there – then it goes back to your basic values, if you believe in religion or versus evolution [GESTURE generally with both open hands towards me]. I mean, if you – ask a basic question, you know "Did God put us here or not". But, you know, that's a – different level [GESTURE with open hands towards me, and then away from the graphic]. But this is science [GESTURE with open left hand at graphic], so we're here in a science – museum [GESTURE with open hand generally graphic] – so, um, it's important to understand the science [GESTURE rolling gesture with open hands towards graphic], um, aspect of it.

I: Perfect. Thank you – that's all the questions I have.

Camilla (aged 35); Participant 006 – branched tree

Date: 02/10/2014 Participant #: 006_02102014_3_BR Duration: 6 minutes, 42 seconds

I = interviewer; P= participant

I: What do you think this picture is trying to show?

P: Show [pause] the ancestors of modern day [rising tone] – mammals.

I: How do you think that happened? What you see here.

P: [pause] Big picture? Little picture – what do you mean?

I: Any picture. All pictures.

P: Um, just to show you how they evolved. So [pause] yes. [pause] Evolution – it's how it happened [laughs].

I: So, what do you see here? Tell me about what you see displayed in this graphic?

P: Um, the hippopotamus is not related – uh, not as closely related to the whales as, um [pause] basically showing when things diverged [GESTURE palms together at about 55 million years and then spread out] – so, um, they have a common ancestor [GESTURE hands brought back together] but that's a long long time go, and then you can see the similarities [GESTURE open left hand flat palm down right hand supporting around two bottom branches of right branch], um – and the animals on the right side [GESTURE at baleen and toothed whales fingers splayed], see, you know, their ancestors [GESTURE at extinct taxa down along right side], how they evolved. And then, um, a big leap here on the bottom [surprise] – so I assume that there is a whole bunch of animals not shown [GESTURE with open closed hands from bottom of graphic, right remains and left moves up along the branch].

I: What do you think this picture is trying to show about *Balaenoptera musculus* and

Tursiops truncatus [POINT to taxa]?

P: I think how closely related they are. Um – I think it shows their similarities. And it kinda contrasts them with how differently things could have turned out [POINT at hippo], you know, if they'd gone [pause] become a land animal [GESTURE generally with open left hand at right, then bottom, then left side of graphic].

I: And, what do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa]?

P: [pause] *Elomeryx* doesn't look like it spent much time in the water. So I think – let's see – we have quite a bit of contrast between *Elomeryx* and *Hippopotamus*, but I think looking at this ancestor from 55 million years ago [POINT with right hand with left brought to right] to *Elomeryx* [POINT with left hand at *Elomeryx*] they look much much much more – I mean they almost look the same [TRACE with open left hand from *Elomeryx* to Artiodactyl ancestor, and then back], so I think it's showing how much of a change [COMPARE with open left hand in claw shape at area between *Elomeryx* and hippo] can happen in a short amount of time, relatively short amount of time.

I: Change be [talking over each other]

P: I have to assume [talking over each other]

I: Sorry, go ahead.

P: I have to assume now that I am looking at it more closely [GESTURE general gesturing with both hands at left side of graphic] – I had not looked this silhouette [POINT at Artiodactyl ancestor] that closely compared to *Elomeryx* – it's not that there's a whole bunch of things missing, it's that it had not changed [GESTURE with open left hand at Artiodactyl ancestor and up left branch, and then back and forth].

I: OK, so you think this is showing that that it had not changed. So, you are looking at the differences between this one [POINT at Artiodactyl ancestor] and that one [POINT at *Elomeryx*]? Compared to this one [POINT at *Elomeryx*] and that one [POINT at *Hippopotamus*].

P: Right – so I am expecting to see if, if there were an animal illustrating [GESTURE open hands at middle part of graphic towards outside] – the, animals in between [GESTURE both open hands at artiodactyl ancestor] the ancestor and *Elomeryx* [GESTURE open left hand to *Elomeryx*] I would expect it to look the same [GESTURE generally in middle part of graphic], and so if there was a parallel to each one of these three [GESTURE with both hands at *Pakicetus*, then left hand moves to *Elomeryx*; then POINT with right hand finger to *Pakicetus*, then *Rodhocetus*, then *Dorudon*, then *Pakicetus*] I'd expect it to pretty much, pretty much [emphasis] look the same as *Elomeryx* [POINT with right hand finger at Artiodactyl ancestor, then at some point along the left branch, then *Elomeryx*].

I: OK.

P: That is my description. [pause] Based on that silhouette – that looks [leans in close to look] – just like *Elomeryx* [laughs].

I: Now, at one time there was one species of animal shown here [POINT to Artiodactyl ancestor] and now there are hippopotamuses, baleen whales and toothed whales [POINT to taxa]? How would you explain this?

P: Evolution [laughs]. Um [pause] they, well, animals adapted to different environments [GESTURE with open hands palm up at graphic]. So, I'm not sure – based on just this graphical [indistinct], how do I explain that [GESTURE sweeping gesture with open left hand at graphic]?

I: Yeah, just how do you explain, um, that there can be one species [POINT at *Elomeryx*] – in the past – and then you have multiple species [POINT at hippo, then baleen whale, then toothed whale] – currently?

P: I just explain that by environmental factors. So – food available, habitat available – predators, climate – just everything in the environment – that impact that.

I: Now, is there anything that you find interesting about the graphic that we haven't talked about? Anything that perhaps jumps out to you or you think is of particular interest to you [GESTURE sweeping gesture with open right hand at graphic]?

P: [pause] Umm. Anything at all?

I: Mm-hmm.

P: [long pause] No. Mm.

I: Now, if you had to tell someone about this graphic, what would you tell them? If I invited someone in and I said "can you tell them about this graphic".

P: Uh, I'd start at the bottom. And I'd – because – well, I'd say this is showing [GESTURE with open hands and then generally in air] what these animals. Well, I guess maybe I would start at the top [GESTURE at terminal taxa]. Showing that these animals. How, how they're related to this common ancestor [POINT open left hand at Artiodactyl ancestor], and showing the changes that took place over time [GESTURE with open hands in the air]. So, and then point out the timeline. Um, I'm not sure as far as the scale of the timeline – it seems to be covering 55 million years. It looks like it's fairly to scale [GESTURE with open hands in air]. Hmm? Actually, it's not. Because of the, I think, because the animals [POINT at right side of graphic]. So this space, I mean to me, I guess, I notice this spacing is 36 million – that's only, what maybe, 24 million

[GESTURE/POINT (unable to see) with left hand at timelines] – but it takes up more physical space [GESTURE with open right hand at Artiodactyl ancestor]. So I would point out to a viewer – that's not to scale.

I: OK, that the timeline is not to scale? [talking at the same time]

P: That the timeline is not to scale. [talking at the same time]. Mm-hmm.

I: And then you said that this shows how they are related over time?

P: Mm-hmm.

I: And how they are all related over time? Or particular ones are related over time?

P: Well, just these three species [POINT with fingers on left hand at terminal taxa] – I'm assuming, you know, there's many many many more species [GESTURE both hands expanding out] that have this common ancestor [GESTURE with open right hand palm down at artiodactyl ancestor]. So, it' just how it even, the similarities and differences between these three particular, these two whales and a hippopotamus [GESTURE with grasping hands].

I: And how would describe – you've talked about these ones at the top [POINT at terminal taxa] – how would you describe these taxa's relationship to that story or explanation [POINT at *Elomeryx* and extinct taxa on right side from top to bottom]?

P: Well at some point they diverged [GESTURE with open right palm at graphic]. I'm assuming this is where [POINT with open left hand at Artiodactyl ancestor] – they diverged 55 millions years ago. Um, if I had to explain this graphic to someone, I might say there's a lot of other animals not shown [GESTURE with hands palm down and close to each other, then to open hands in front of graphic]. So.

I: OK. And the ones that are shown?

P: Uh. Well, they must be illustrating – some point [GESTURE with open left hand along right branch from bottom up to whales] about the two whales [rising tone].

I: And what do you think that point might be?

P: [long pause] Maybe that all whales have these common ancestors [rising tone] [POINT with left hand finger at *Dorudon*].

I: Ok, is there anything else that – you want to tell me about this graphic?

P: Um, I don't think so.

I: Perfect, Thank you.

Melissa (aged 17); Participant 007 – branched tree

Date: 02/16/2014 Participant #: 007_02162014_2_BR Duration: 5 minutes, 10 seconds

I = interviewer; P= participant

I: What do you think this picture is trying to show?

P: It's definitely trying to show the evolution of – animals from – the past to today [GESTURE with open right hand palm up generally upwards at graphic].

I: How do you think that happened?

P: Well [pause] eh, through time [GESTURE with open right hand palm up generally upwards at graphic] and changes in the body.

I: What kinds of things do you see shown in this graphic [GESTURE open right hand general gesture at graphic]? What do you see shown here?

P: You can see animals that have gone from having – legs to seemingly to having fins. As well as animals going from having longer legs to shorter legs [GESTURE with open right hand palm up generally upwards at graphic].

I: Hm. Is there anything else that you see?

P: Um, you can also see how – um [elongated] – that, um [GESTURE with open right hand palm up generally at graphic], *Elomeryx* [GESTURE with open right hand palm up generally at graphic] it went from, as it became hippopotamus and that given a shorter tail.

I: So, what do you think this picture is trying to show about *Balaenoptera musculus* and *Tursiops truncatus* [POINT to taxa]?

P: It's showing that, uh, they evolved from creatures that have had legs – or webbed feet [GESTURE with open right hand palm up generally at graphic] at least at one point.

I: And how do you think it is showing that?

P: It's showing that be, because the lines are connecting [rising tone somewhat] [GESTURE with both hands palm up generally at graphic and then clasps hands].

I: OK – these lines up here? [POINT left hand finger along baleen and then toothed branches, from top to node]

P: Mm-hmm.

I: What do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa]?

P: It's showing that even *Elomeryx* is kinda related to the hippopotamus it's not as closely related as [pause] [GESTURE from clasped hands to an open right hand generally gesture at graphic] well, or it's closely, more closely related to the hippopotamus than, uh [GESTURE from grasped hands to an open right hand generally gesture at graphic and then back to clasped hands], any of the other animals.

I: So, you think it's showing you that *Elomeryx* [GESTURE with open right hand at left side of graphic near *Elomeryx* node] is more closely related to the hippo than to any of the other ones [GESTURE with open right hand generally at the right side of graphic]?

P: Yes.

I: OK.

I: And how do you think it shows you that?

P: It's showing us that because *Elomeryx* is only connected to the hippopotamus and the – Artiodactyl [GESTURE from grasped hands to an open right hand generally gesture at graphic and then back to clasped hands], whereas the others are all connected to, uh, the baleen whale and toothed whales [GESTURE from grasped hands to an open right hand generally gesture at graphic and then back to clasped hands].

I: Now, at one time there was one species of animal shown here [POINT to Artiodactyl ancestor] and now there are hippopotamuses, baleen whales and toothed whales [POINT to taxa]? How do you explain this?

P: Well evolution, and of course changes in atmosphere. Whereas, uh, perhaps if one was stuck on, uh, during Pangaea, if the continents split apart it could have got into different environments [GESTURE from grasped hands to open hands palm up, then palm down, and then back to clasped hands].

I: Is there anything else that you think is interesting about this graphic?

P: I think it's definitely interesting how, um, even – how even though, the, uh, hippopotamus and baleen whales are – they are all – from the same creatures they ended up in totally different areas [GESTURE from grasped hands to an open right hand generally at graphic, and then both hands palm up gesture generally at graphic, and then back to clasped hands].

I: So, in terms of environment, different environments?

P: Mm-hmm.

I: Now, if you had to tell someone about this graphic – so, if I invited someone in and I said "could you tell them about this graphic", what would you tell them [GESTURE with open right hand generally at graphic]?

P: Uh, I would explain how this is showing that the, uh, even though there are many species of animals today [GESTURE from grasped hands to both hands spread apart palm and then back to clasped hands], we can all trace them back to – uh, a smaller group of species.

I: To a smaller group?

P: Mm-hmm.

I: I asked about, uh, baleen whales and toothed whales and what it was trying to show you,

P: Mm-hmm.

P: and then I asked you about *Elomeryx* and *Hippopotamus* [POINT to taxa]. Do you think they're showing you the same kinds of thing or different things?

P: Different things. You can see here that the, uh, baleen whales and the toothed whales [GESTURE from grasped hands to an open right hand gesture upwards at graphic and then back to clasped hands] are closely related today. Whereas *Elomeryx* and hippopotamus are connected, uh, [GESTURE from grasped hands to open hands spread slightly apart and then back to clasped hands] over millions of years.

I: Is there anything else that you would like to tell me about this graphic?

P: I think I'm good.

I: OK – that's great.

Mary (aged 41); Participant 008 – linear tree

Date: 02/17/2014 Participant #: 008_02172014_3_L Duration: 6 minutes, 15 seconds

I = interviewer; P= participant

I: What do you think this picture is trying to show?

P: Um [pause] how, uh, different animals evolved from the same ancestor.

I: And, how do you think that happened?

P: Uh [pause] um – you know, natural selection [laughs]

[A brief exchange to remind participant that they could stand, they indicated that they had a broken toe and preferred to sit]

uh, natural selection, they've, um, things, eh, different climates evolved different features to help them sort of adapt and survive in their environment [GESTURE with open hands generally outwards]. We have aquatic – and we have terrestrial [GESTURE with open hands generally outwards].

[A brief exchange and moved graphic closer to the participant]

I: So, what kinds of things do you see shown in this graphic [GESTURE open right hand general gesture at graphic]?

P: Well, I see you have, um, things that we would not, we would be familiar with here [POINT open left hand and touch top left of graphic] – and, for today – and then things – that look similar but maybe not familiar with things that we currently see [POINT with open left hand at *Elomeryx* and then toward extinct taxa on right]– because the, these, I mean especially these [POINT with left hand finger at *Dorudon*, then *Rodhocetus*, then *Pakicetus*] – they seem to get a little [pause] uh [pause] farther [GESTURE with open hands moved apart] from what we would expect from today. I'm surprised there's not more graphics here though [POINT with left hand finger along section of left branch without taxa] – it's kinda this big jump from here to here [POINT with left hand fingers at Artiodactyl ancestor, then *Elomeryx*].

I: So, to show more – different things [GESTURE open right hand to left side of graphic]? [talking at same time]

P: It seems unbalanced. [talking at same time]

I: It seems unbalanced.

P: Yeah.

I: Now, what do you think [talking at same time]

P: That does look [POINT with left and finger at *Elomeryx*, then Artiodactyl ancestor] [talking at the same time]

I: I'm sorry – go ahead.

P: That does look very similar to that [POINT with left and finger at *Elomeryx*, then Artiodactyl ancestor, then back to *Elomeryx*]. So, maybe there wasn't – a lot of evolution there [rising tone].

I: So, you think the – the lack of other things here is maybe showing you that something didn't happen [GESTURE with open right hand at section of left branch without taxa]?

P: Yeah [GESTURE open left hand generally outward].

I: OK.

I: What do you think this picture is trying to show about *Balaenoptera musculus* and *Tursiops truncatus* [POINT to taxa]?

P: Well, the, the, the [pause] graphics – I mean the, the visual representation – they have the same coloring, they have the, you know similar body type, ones much [emphasis] larger

[GESTURE with open hands generally outward, then clasped, then outward again] – I assume much larger, for it to scale, to each other – um, but there, they evolved from the same [GESTURE from clasped hands to an open left hand generally outward] – ancestor from here [POINT at *Dorudon*].

I: What do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa]?

P: Between these two? Well [pause] that's a lot [emphasis] of change. [pause] Between – I mean, for 36 million years ago [POINT with left hand finger at *Elomeryx*, then hippo] – between that, those two.

I: So, it's – you think it's showing you a change between this one [POINT at *Elomeryx*] and that one [POINT at hippo]?

P: Yeah.

I: Now, at one time there was one species of animal shown here [POINT to Artiodactyl ancestor] and now there are hippopotamuses, uh, baleen whales and toothed whales [POINT to taxa]? How do you explain this?

P: [pause] Well, they adapt, adapted, they needed to adapt to, um, survive in their environment. So they would, um – through natural selection different – characteristics would evolve and um, be propagated, cause they would survive [GESTURE with open hands generally outwards] – and they would be, go on to, father – which propagate the species, so those characteristics would be dominant – um, and then they kept evolving depending on the climate they were in, depending on – the environment, how the Earth changed around them.

I: Is there anything else that you think is interesting about this graphic?

P: [long pause] Um, these lines kinda look like equal signs – to me [rising tone] [POINT with left hand fingers to today timeline just before hippo, then area between hippo and baleen whale].

I: These lines? [POINT with open right hand to middle and right part of 36 million year old timeline]

P: So, its' almost like the hippopotamus is equal to the blue whale [rising tone] [POINT with left hand fingers to baleen whale and hippo, then back to whale]. [long pause] The timeline I mean [indistinct].

I: If you had to tell someone about this graphic, what would you tell them [GESTURE open right hand generally at graphic]?

P: [long pause] Um [long pause] I would tell them that – there are, uh, I mean, it's, it's a, its' like a [GESTURE with open hands palm down generally, then palm up and upwards and outwards], kinda like a family tree – but you start out with one [POINT left hand fingers at Elomeryx and then move along left branch] and you can tell how the species has, are, have evolved – separately but all going back to the same ancestor [GESTURE with open hands generally]. And that's just a small representation of the entire project [laughs] [GESTURE with open hands generally].

I: So, only part.

P: Yeah.

I: And, what would you tell them about baleen whales and toothed whales [POINT with open right hand at taxa]?

O: Hm. They're more related than say the hippopotamus and the baleen whale.

I: And what would you tell them about *Elomeryx* and hippopotamus [POINT with open right hand at taxa]?

P: I would say that, uh, *Elomeryx* is an ancestor of the hippopotamus.

I: Is there anything else that you would like to tell me about this?

P: Um, I'd be interested to know where these, where regionally the animals are found [GESTURE with open hands generally] – I mean, even, eh, the ones that could [POINT with left hand fingers at *Dorudon*], cause I kinda know, you know, where those might be [POINT with left hand fingers at hippo, generally at whales, and then down into middle of graphic] – or actually, even between whales [GESTURE with left open palm up] – the baleen whale and the toothed whales, if they're in different parts of the oceans, one's a cold water [GESTURE continue gesturing with left hand palm up], I mean, colder than the other. Um, and I would like to know if these are all aquatic animals [POINT with left hand fingers at *Dorudon*, then *Rodhocetus*, then *Pakicetus*], cause that [POINT at *Pakicetus*] doesn't – I guess he has webbed feet, that would indicate aquatic – but from here to here [POINT at Artiodactyl ancestor, then *Pakicetus*] I think it would be interesting to see um [indistinct].

I: To find out more information about what types of habitat, but also geographically where they lived?

P: Yeah. Mm-hmm.

I: OK. That's all the questions I have about this graphic.

Ann (aged 11); Participant 009 – branched tree

Date: 02/17/2014 Participant #: 009_02172014_1_BR Duration: 7 minutes, 10 seconds

I = interviewer; P= participant

I: What do you think this picture is trying to show?

P: Um [pause] like, how all the animals evolved from something [GESTURE with right hand generally palm down]. So like this one [POINT with left hand fingers at Artiodactyl ancestor] and then these [TRACE with left hand fingers along left branch to *Elomeryx* node; then TRACE back down branch and up right side], this [POINT at *Pakicetus* node], and then that evolved from it [POINT at *Pakicetus*], and that [TRACE along branch from *Pakicetus* to *Rodhocetus* node to *Rodhocetus*] evolved from those [POINT at *Pakicetus*, then TRACE up branch to *Dorudon*], and then yeah whatever [GESTURE generally at right branch, then left branch].

I: OK, so you think, uh, that [POINT at *Pakicetus*] evolved those [POINT at *Pakicetus* node] or that [POINT at *Rodhocetus*] evolved from those [POINT at *Pakicetus*]?

P: Oh, um, it goes up [GESTURE with left hand fingers generally up along right branch; then POINT at *Pakicetus,* then to toothed whale]. So the, this one [POINT at Artiodactyl ancestor] – that [POINT at *Pakicetus*] evolves from that [POINT at *Pakicetus*, then TRACE along branch and POINT at *Rodhocetus* node], and then that [POINT at *Pakicetus*] evolves from that [POINT at *Rodhocetus*]. [stops and puts left hand to other hand] Yeah, so this goes up [TRACE along bottom branch up right side to *Pakicetus* node], so this one [POINT at *Rodhocetus*] evolves from this one [rising tone] [POINT at *Pakicetus*] and then this guy [POINT at *Dorudon*].

I: And, how do you think that happened?

P: [pause] Uh. I don't know [laughs]. Just – I don't know, over time they got used to different places [rising tone], I guess [rising tone]. I don't know.

I: What kinds of things do you see shown in this graphic [GESTURE with open right hand general gesture at graphic]?

P: Um. [pause] Well, like what do you mean [GESTURE interlocked fingers]?

I: So, just tell me about anything you see shown [GESTURE with open right hand at graphic]? What do you think we're trying to show here [GESTURE with open right hand at graphic]?

P: Um. [long pause] I don't know. Um – well, how – well, there's um – um [GESTURE hands together then apart and generally gesture] – well – I don't know, maybe how whales and hippopotamuses when they go really way back they are related [GESTURE interlocked fingers occasional wringing] I guess [rising tone].

P: Hmm.

P: I don't know [laughs].

I: It's whatever you think is what I am interested in.

I: So, what do you think this picture is trying to show about *Balaenoptera musculus* and *Tursiops truncatus* [POINT to taxa]?

P: Um. [long pause] Maybe – they both evolved from the same thing – but if they lived in different places, they kind of [GESTURE interlocked fingers to open hands]. Like if they lived in different, ecosystems I guess [rising tone].

I: OK, so you think they, you think that both of these [GESTURE with open right hand at baleen and toothed whales] evolved from the same thing.

P: Yeah.

I: OK. But that they're different?

P: Yeah.

I: What do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa]?

P: Um. Well the hippopotamus, this guy [POINT left hand fingers at hippo] evolved from this guy [POINT *Elomeryx*], but – um – um, what's it called. Um, I don't know what I was going to say, ah [frustrated]. But, um, it, both of them evolved from this guy [POINT at Artiodactyl ancestor] even though these two look severely different [POINT at *Elomeryx*, then hippo].

I: OK, so these two look really different [POINT at hippo, then *Elomeryx*], but you think they both evolved from this one [POINT at Artiodactyl ancestor]?

P: Yeah.

I: And, you said that you think that this is showing that *Elomeryx* [POINT at *Elomeryx*], and hippopotamus [POINT at hippo] – that hippopotamus [POINT at hippo] evolved from *Elomeryx* [POINT at *Elomeryx*] – or something else?

P: Uh, yeah that's right [GESTURE right hand towards me].

I: OK. And how do you think that happened?

P: Um. [pause] Maybe [pause] – this one [POINT at hippo] started going somewhere else and travelling – like in another direction and exploring a different place [pause] [GESTURE right hand fingers rubbing palm of left hand] and then the other, and then it started changing over time [POINT with right hand finger at top left of graphic, then interlock fingers].

I: Do you have any idea of how [emphasis] it might change over time?

P: Hmm [pause] I don't know.

I: Now, at one time there was one species of animal and now there are hippopotamuses, baleen whales and toothed whales [POINT to taxa]? How would you explain this to someone?

P: Um. [pause] Um. [pause] I don't know [GESTURE cross arms] – um.

I: Well, how do you think you – would explain to someone you can go from having one animal [POINT at artiodactyl ancestor], one animal in the past [POINT at Artiodactyl ancestor] then to having three different animals today [POINT at hippo, then baleen whale, then toothed whale].

P: Well, maybe. It looks like this one [POINT with left hand finger at *Elomeryx*] starts going in the waters kind of [rising tone] [GESTURE both hands palm down]. Like slowly started going into the water [POINT at *Pakicetus*], and this one [POINT at *Elomeryx* node] kind of travelled more on land, but then yeah [TRACE with left hand fingers along branch to hippo] – and then this one just kept going farther [GESTURE with right hand fingers around *Rodhocetus* and *Rodhocetus* node, then up branch] – I don't know.

I: OK. So you think that this one, um, went towards the water [POINT at *Pakicetus* and then move hand up], and that one [GESTURE towards left side of graphic] stayed on land?

P: [nods]

I: What kinds of things do you find interesting about this graphic [GESTURE with open right hand palm down generally at graphic]?

P: Um. [pause] Well – that there's only, um, one thing and that a bunch of things, like a bunch of things can evolve from it and, um, they can all look very different.

I: And look different.

I: If you had to tell someone about this graphic – so, if I invited someone in and said "What can you tell them about this graphic?" – what would you tell them [GESTURE with open right hand generally at graphic twice]?

P: Um. Um. So there's – one animal and then this thing – so slowly this evolves [GESTURE with right hand fingers along left bottom branch], but then this one evolved faster [POINT with right hand at left branch of *Pakicetus* node], and then this one [POINT at *Rodhocetus* node], and then this one [POINT at *Dorudon* node], and then finally [POINT at *Dorudon*] once you get to this one [POINT at *Elomeryx* node], this one fully evolved [POINT at *Elomeryx*]. But this one is starting to evolve [TRACE from *Elomeryx* node to hippo], and then it splits off into these [TRACE from whales node to baleen whale and then toothed whale], and then they all, these three evolve [POINT at hippo, then baleen whale, then toothed whale] – like at the same time, ish.

I: OK. So you think this one evolves [TRACE from *Elomeryx* node to *Elomeryx*], and then that one [TRACE from *Elomeryx* node to hippo] evolves…

P: Yeah [POINT at *Elomeryx*], so one – so, like these evolve slowly [TRACE with fingers on each hand simultaneously from *Elomeryx* node to *Elomeryx* (left), and *Elomeryx* node to hippo (right)], but this one takes longer [POINT at hippo]. So once this is fully evolved [POINT at *Elomeryx*], then this [POINT at *Elomeryx* then *Elomeryx* node, then TRACE from node to hippo] gets off of that [POINT at hippo].

I: OK. And the same thing here [POINT at *Pakicetus*, then *Pakicetus* node]?

P: Yeah.

I: Is there anything else that you would like to tell me about this graphic?

P: Um, not really.

I: OK. Perfect. That’s all the questions I have.

Andy (aged 12); Participant 010 – linear tree

Date: 02/20/2014 Participant #: 010_0220014_1_L Duration: 4 minutes, 44 seconds

I = interviewer; P= participant

I: So, my first question is, what do you think this picture is trying to show?

P: Evolution.

I: Evolution of [GESTURE with open right hand generally at graphic]?

P: Uh – a whale.

I: And, how do you think that happened?

P: Um, over time adaptation to environment and, changes in maybe – predators – or, and uh, their food.

I: OK. Now, what kinds of things do you see shown in this picture [GESTURE with open right hand general gesture at graphic]?

P: Um, I see like a, a whale – and then it uh, evolving legs, maybe. Um, eventually – and then becoming a hippopotamus.

I: So, you would see a whale evolving legs and then becoming a hippopotamus [GESTURE with open right hand generally at graphic]?

I: What do you think this picture is trying to show about *Balaenoptera musculus* and *Tursiops truncatus* [POINT to taxa]?

P: Um – that they're similar, but, um – they're similar but, uh, they look different but they're in like the same family.

I: So, you think they are in the same family?

P: Yeah.

I: And if someone asked what does the same family mean, what would you say?

P: Uh – like sort of not the same species, but, um, like a cousin [GESTURE with open hands generally at graphic] – sort of.

I: OK.

I: What do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa]?

P: Um – that *Elomeryx* sort of developed over time and became sort of amphibious – uh, like a hippopotamus is today, not just a land animal [GESTURE with left hand generally at left side of graphic].

I: So. You think that *Elomeryx* became more amphibious [GESTURE with open right hand palm down then palm up generally at graphic]?

P: Yeah.

I: Now, at one time there was one species of animal and now there are hippopotamuses, baleen whales and toothed whales [POINT to taxa]? How do you explain this?

P: Um. [pause] I think maybe – that animal, um, could have – sort of evolved into [stops] [GESTURE with open left hand generally at graphic]. Like half of those animals evolved into *Elomeryx* [POINT with open left hand at *Elomeryx*] and half of those [GESTURE with open left hand at Artiodactyl ancestor] could have evolved into these [GESTURE with open right hand at right branch upward], whale like things, whale like animals [GESTURE with right hand at right side of graphic].

I: So, half of these [POINT open right hand fingers at Artiodactyl ancestor]?

P: Yeah.

I: OK.

I: Is there anything else you find interesting about this graphic [GESTURE generally open right hand palm down at graphic]?

P: Uh, well these look like predator animals [GESTURE with left hand palm down at right branch taxa] – like – predators. And then these [GESTURE with left hand palm up at baleen whale], I mean, they're, they eat like krill and [pause] stuff [GESTURE with open left hand generally at graphic].

O: So you think these are predators [GESTURE with right hand fingers along right branch from *Dorudon* to *Pakicetus*] and this one is not [POINT at baleen whale]?

I: Yeah.

I: And what do you think is the connection between these [GESTURE with right hand fingers along right branch from *Pakicetus* to *Dorudon*] – and that one [POINT at baleen]?

P: Um [pause] it, that they sorta had to evolved on what to eat. And they sorta changed [GESTURE with open left hand generally outward] from being a predator to, like – I, I don't know the word for eating krill, like a baleen [indistinct] [GESTURE with open left hand generally at graphic].

I: So like being a herbivore – or krill are animals, but they're not the same as being a carnivore.

P: Yeah.

I: OK.

I: Now, if you had to tell someone about this graphic, what would you tell them [GESTURE with open right hand generally at graphic]?

P: Um. Evolution can change a lot of things – and, that, some things can maybe not look as, can look different and sorta – change over the time.

I: So look different.

P: Yeah.

I: Now if I asked you – if I brought someone in here and I said "Can you tell them what the, the purpose or role of this graphic is", what would you say?

P: Um. [pause] To show people that, uh, this is like, um – that this wh, this is, uh, what can happen over the course of a long period of time [GESTURE with open left hand generally outward].

I: Over a long time.

I: Is there anything else you want to add about this graphic, or maybe something you think is interesting that I haven't asked you?

P: Um [pause] – not really.

I: OK.

Samantha (aged 53); Participant 011 – branched tree

Date: 02/20/2014 Participant #: 011_0220014_3_BR Duration: 5 minutes, 15 seconds

I = interviewer; P= participant

I: So, my first question is, what do you think this picture is trying to show?

P: Evolution.

I: Evolution of?

P: [pause] Of [pause] Artiodactyl.

I: And, how do you think that happened [GESTURE with open right hand generally at graphic]?

P: I think [pause] given whatever environment it lived in, and how that changed it evolved to continue to, um, to live, and survive, and procreate, and, um – ultimately became hippopotamus and baleen whales, and toothed whales [GESTURE with open left hand palm up generally at graphic].

I: So, what kinds of things do you see shown in this graphic [GESTURE with open right hand general gesture at graphic]?

P: [pause] Um. [pause] Well the fact that something that was four-legged evolved in to, uh, um [pause] along two different trajectories [GESTURE with open left hand generally at graphic] to another, to a four, four-legged [GESTURE with open left hand generally at graphic] and also to a sea [GESTURE with open left hand palm up generally at graphic], um – a sea animal.

I: What do you think this picture is trying to show about *Balaenoptera musculus* and *Tursiops truncatus* [POINT to taxa]?

P: That they're related.

I: What do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa]?

P: They're a little more distantly related.

I: Now, at one time there was one species of animal and now there are hippopotamuses, baleen whales and toothed whales [POINT to taxa]? How do you explain this?

P: I would imagine that where artiodactyl, um – lived at some point it needed to, um – in order to survive, it needed to be able to, um, live in water – and in some places it didn't.

I: Is there anything else that you think is interesting about this graphic [GESTURE with open right hand palm down generally at graphic]?

P: Um. [long pause] The graphic per se or what it's?

I: Anything.

P: Um, I think it's interesting that it went from four-legged to have webbed [GESTURE with open left hand palm down generally at graphic, then with both hands open, palm down and fingers spread out, held close to each other], you know, webbed, um, feet until it ultimately became whale [GESTURE open left hand palm down up towards whales], I think that's kinda interesting. I mean, this [POINT with left hand fingers at *Elomeryx*] doesn't look too far off from that [POINT left hand fingers at artiodactyl ancestor] – just visually – as much as it [POINT with left hand fingers at *Elomeryx*] looks different from a hippo [POINT with left hand fingers at hippo].

I: So you think that – this is a much bigger difference, or a more dramatic [GESTURE with open right hand generally at right side of graphic]?

P: Oh, yeah. Yeah.

I: If you had to tell someone about this graphic, what would you tell them [GESTURE with open right hand generally at graphic]?

P: Um. [long pause] That just because something – currently lives in the sea, it hasn't always lived in the sea.

I: What do you think is the – role or the purpose of this graphic [GESTURE with open right hand generally at graphic]?

P: [long pause] To explain how species evolve.

I: Is there anything else you'd like to tell me about this graphic, something that maybe I haven't asked you about [GESTURE with open right hand generally at graphic]?

P: No.

I: OK. That's all the questions I have about this graphic.

Lucy (aged 14); Participant 012 – linear tree

Date: 02/21/2014 Participant #: 012_02212014_2_L Duration: 3 minutes, 50 seconds

I = interviewer; P= participant

I: So, my first question is, what do you think this picture is trying to show?

P: Um, like the evolution [GESTURE with open left hand, palm down and fingers spread palm, generally at graphic] – of the one down here [POINT with left hand finger at *Elomeryx*] into different species [GESTURE with open hands, palm down and fingers spread out, upwards and outwards generally around top of graphic].

I: OK, the evolution of this one down here [POINT right hand fingers at artiodactyl ancestor] into other species?

P: Mm-hmm.

I: And, how do you think that happened?

P: Um. [pause] By, um – like isolation of different parts of that [GESTURE with open hands, palm down and fingers spread out together and moved apart several times], um, main, the ancestor [POINT with left hand finger at Artiodactyl ancestor] or [drawn out] like natural selection [GESTURE generally downward with open left hand, palm down and fingers spread] and stuff like that [laughs].

I: So, isolation by different parts of the ancestor [POINT right hand fingers at Artiodactyl ancestor]?

P: Mm-hmm.

I: So, what kinds of things do you see shown here [GESTURE with open right hand generally at graphic]?

P: Um. [pause] I see – the ancestor – evolving into more – like – like aquatic animals

[GESTURE general at graphic with open left hand and fingers spread, palm up then turned down, around top left of graphic, then at up and down around top right of graphic] and then also [GESTURE with open left hand around top left of graphic], like, like um, I, I don't know – like ones with four legs [GESTURE downward in air with open hands, palm down and fingers spread].

I: OK. So, ones that are more terrestrial? More on land? OK. So, you see the ancestor evolving into more aquatic, but also more terrestrial [GESTURE with open right hand generally at graphic].n

P: Mm-hmm.

I: What do you think this picture is trying to show about *Balaenoptera musculus* and *Tursiops truncatus* [POINT to taxa]?

P: Um. That they're different species but they're also related to each other, by a common ancestor [GESTURE downward with open left hand and fingers spread].

I: OK. What do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa]?

P: Um. That the hippopotamus [GESTURE with open hands, palm sideways and fingers spread generally in air] evolved from *Elomeryx*.

I: Now, at one time there was one species of animal and now there are hippopotamuses, baleen whales and toothed whales [POINT to taxa]? How would you explain this?

P: Um [pause] by different sections of the ancestor [GESTURE generally in air with each hand, palm down and fingers spread, together and then moved apart to indicate sections] getting, separated, or maybe, um, different groups of the ancestor moving into different parts of the world [indistinct] [GESTURE generally downwards in air with both hands, palm down and fingers spread] – where they need, um, different traits to survive in different climates or [GESTURE generally in air with open left hand, palm down and fingers spread].

I: OK.

P: things like that [trails off].

I: Is there anything else that you think is interesting about this graphic [GESTURE generally at graphic with open right hand]?

P: Um [rising tone]. I think it's interesting the, just kinda [GESTURE with open hands, palms turned outward and fingers spread towards each side of graphic], it, it really splits [SPLIT use index finger on each hand to indicate a split in front of the graphic] and you can tell – there's the, like, terrestrial like you said [GESTURE with open left hand at top left side of graphic], and then the, aquatic [GESTURE with open left hand at top right side of graphic].

I: OK.

P: How, they're like really different – looking [GESTURE open hands fingers spread generally at graphic] – but they came from the same ancestor.

I: Now, if you had to tell someone about this graphic, what would you tell them [GESTURE open right hand generally at graphic]?

P: Um. [pause] That [pause] Um. [pause] Like what it's trying to show or just?

I: Yeah, if I invited someone and I said " Can you tell them what this graphic is all about", what would you tell them?

P: Um. That like what that ancestor animal [POINT with open left hand at Artiodactyl ancestor] evolved into [GESTURE generally in air with both hands upwards] over time.

I: Is there anything else that you want to tell me about this graphic [GESTURE with open right hand generally at graphic]?

P: Uh [rising tone]. I like that it's, colorful and it shows the different, um, years [POINT with left hand finger at 36 million years, then generally towards lower timelines, then at today, then back down], like it specifies how old the different species are [GESTURE with open left hand generally at timeline], kinda.

I: Great. Thank you. That's all the questions I have about this graphic.

Sarah (aged 47); Participant 013 – linear tree

Date: 02/21/2014 Participant #: 013_02212014_3_L Duration: 4 minutes

I = interviewer; P= participant

I: So, my first question is, what do you think this picture is trying to show?

P: The, the ancestry of [pause] current [GESTURE with left hand finger generally across top of graphic], um, mammals. The hippopotamus, baleen whales and toothed whales.

I: And, how do you think that happened [GESTURE with open right hand at graphic]?

P: Um, through evolution for the hipp, hippopotamus [POINT with left hand finger at hippo], um, going back to the *Elomeryx* [POINT with left hand finger at *Elomeryx*] and then the Artiodactyl [slowly] [POINT with left hand finger at Artiodactyl ancestor] – and then the baleen whales split [SPLIT separate first two fingers of left hand to show split at *Dorudon* and then moved upwards] at the *Dorudon* [POINT with left hand finger at *Dorudon*] – but, but prior [LINE left hand finger down along right branch] to that they shared *Rodhocetus* [slowly], *Pakicetus* [slowly], back to the shared Artiodactyl [slowly] [POINT with left hand finger at *Dorudon*, then *Rodhocetus*, then *Pakicetus*, and then Artiodactyl ancestor].

I: Now, what kinds of things do you see shown in this graphic [GESTURE with open right hand at graphic]?

P: [pause] What kinds of things?

I: Yeah.

P: Like, pictures? Um [pause] diagramming with the lines [GESTURE with open left hand generally upward at graphic], and um, a timeline.

I: What do you think this picture is trying to show about *Balaenoptera musculus* and

Tursiops truncatus [POINT to taxa]?

P: Um. That they – shared the common ancestor *Dorudon*.

I: What do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa]?

P: That, um, hippopotamus is, um, well that – *Elomeryx* is a direct ancestor of hippopotamus.

I: Now, at one time there was one species of animal and now there are hippopotamuses, baleen whales and toothed whales [POINT to taxa]? How do you explain this?

P: Um. Through evolution [pause] and, um – branching off starting at 55 million years ago [POINT left hand finger at 55 million years ago]. [long pause] So there was one branch in the tree that split hippopotamus and the whales [TRACE with left hand finger from 55 million node up left branch, and then from node up right branch] at 55 million, and then there's another branch [TRACE with left hand finger from 35 million node up left whale branch, and then from node up left side of whale branch] at 35 million, that split the two whales.

I: Is there anything else that you find interesting about this graphic [GESTURE generally with open right hand at graphic]?

P: [pause] Um. I'm wondering if the sizes are all to scale [GESTURE with open left hand generally at graphic] – of the various animals. [pause] And I am thinking not [POINT with left hand finger at hippo], I'm thinking the baleens are usually like really huge compared to hippopotamus [POINT with left hand finger at baleen, then back to hippo a few times].

I: Now, if you had to tell someone about this graphic, what would you tell them? If I said, “What is this graphic all about?” [GESTURE with open right hand generally at graphic].

P: Um [rising tone]. It’s about the ancestry of hippopotamus, baleen whales and toothed whales.

I: Is there anything else you might like to tell me about this graphic, that maybe I haven’t asked you about?

P: Um. No.

I: OK. That’s all the questions I have about the large graphic.

Alexa (aged 37); Participant 014 – branched tree

Date: 02/23/2014 Participant #: 014_02232014_3_BR Duration: 6 minutes

I = interviewer; P= participant

I: So, my first question is, what do you think this picture is trying to show?

P: Um. [pause] How, the – Artiodactyl [slowly and laughs] [POINT with open left hand at Artiodactyl ancestor], um, is the, you know ancient ancestor of all the other animals in the graphic, and that – the ones on top are animals that we can see today that are traced to that initial animal – and then all the little dotted lines shows how they're related and how they kinda progressed through time, and evolved. [pause] And so on one, so I see on one side, see and through water, and then this side here is the animals that evolved on land.

I: And, how do you think that happened [GESTURE with open right hand generally at graphic]?

P: [long pause] Tsk. Over many [emphasis] years, um, the animals adapted to their environment – and, um, their – physical bodies just adjusted and made – necessary – changes so that they would survive.

I: Now, what kinds of things do you see shown in this graphic [GESTURE with open right hand at graphic]?

P: What kinds of things? [long pause] Meaning like what kind of animals or?

I: Just in general. If I asked you what kinds of things do you see shown here [GESTURE with open right hand generally at graphic] – what do you see shown here?

P: [coughs/clears throat] Um. I see, um, animals that once existed, animals that exist today – and a way to – explain how – the animals have changed over time – and – um – that's, what I see.

I: What do you think this picture is trying to show about *Balaenoptera musculus* and *Tursiops truncatus* [POINT to taxa]?

P: They're related. Um – and they're both connected to all of the other animals that are on the right side of the graphic [GESTURE with open left hand at right side of graphic]. Um – somehow they kinda split and evolved differently but we can trace it back to the same animals.

I: What do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa]?

P: Um. I'm not sure. [pause] I mean, if I really sit and analyze like, why it's not just like straight [GESTURE open left held flat upwards at ~45 degree angle and moved in straight line from *Elomeryx* to hippo area of graphic] – but, I see it's kinda curved [TRACE with left hand finger from *Elomeryx* area to *Elomeryx*/hippo node then up right (hippo) branch], I don't know if that means anything [laughs]. Um, but I can tell that – what it's trying to show is the hippopotamus somehow evolved from that, *Elomeryx* animal [rising tone].

I: OK. So you think that hippopotamus evolved from *Elomeryx* [POINT with open right hand at hippo then *Elomeryx*]?

P: Not sure. Um. [pause] I guess yeah, if I just looking at it that's what I would think, that they're somehow connected like that yeah [sniffs].

I: You commented on this [TRACE with right hand finger from *Elomery*x to *Elomery*x node to just past node] not being a straight line though.

P: Yeah. Um – Well – so, this is 47.5 million years [POINT with left hand finger at 47.5 million years ago text, then move across to branch to just below *Elomeryx* node], and then is thirty [TRACE with left hand finger from *Elomeryx*/hippo node to *Elomeryx*], I don't know it just kinda curves back down and then goes up [TRACE with left hand finger from *Elomeryx* to *Elomeryx*/hippo node and up right branch to hippo] instead of [GESTURE open left hand held flat and directed upwards at ~45 degree angle in moved straight line from *Elomeryx* area to hippo area of graphic].

I: So, what do think that might mean, or might be trying to show you?

P: Um [rising tone]. So, this animal evolved over time [POINT with open left hand at Artiodactyl ancestor; then TRACE from Artiodactyl node to *Elomeryx* node] and split off into two different adaptations [rising tone] [TRACE from *Elomeryx* node to *Elomeryx*, then from node to hippo].

I: Now, at one time there was one species of animal and now there are hippopotamuses, baleen whales and toothed whales [POINT to taxa]? How do you explain this?

P: [long pause] Hm. I think I might answer it again, using the same – words. Um, just – started off with a simple – animal – that – um, in order to survive in, like, particular elements and physical environments the bodies changed over time so that they could survive as a species and just kinda branched off so that, you know – obviously this is a land animal [POINT with left hand finger at Artiodactyl ancestor], in order to survive in water [GESTURE with open left hand towards right side]– you need different – body parts and, different kind of body. Um. That's, that's how I see it I guess.

I: Is there anything else that you find interesting about this graphic that maybe I haven't asked you about [GESTURE with open right hand generally at graphic]?

P: Uh-uh. I don't think so. I think it's cool, to see the whale, and the hippopotamus as, you know, two totally different animals, but being connected by a common ancestor.

I: If you had to tell someone about this graphic, what would you tell them? [GESTURE with open right hand generally at graphic].

P: I would tell them that there's a, really cool way to visualize how – animals have evolved on planet Earth over time – and that, you can see – it depicts a lot more complexity with water animals than it does with the land animals, but you can see how the hippo and the whale are connected to this common animal – 55 million years ago.

I: OK.

I: That's all the questions I have about the large graphic.

Ellie (aged 16); Participant 015 – branched tree

Date: 02/23/2014 Participant #: 015_02232014_2_BR Duration: 3 minutes, 50 seconds

I = interviewer; P= participant

I: So, my first question is, what do you think this picture is trying to show?

P: I think it's trying to show evolution – like, where all the animals came from, subgroups.

I: And, how do you think that happened [GESTURE with open right hand generally at graphic]?

P: Um, from the diagram it would look like 55 million years ago, the Artiodactyl ancestor was split up into two groups that we know of, and this, the *Elomeryx* [POINT with left hand finger at *Elomeryx*] was found 36 million years ago and the – *Pakicetus* was found 48.5 million years ago [POINT with left hand finger at *Pakicetus*].

I: OK. Now, what kinds of things do you see shown here [GESTURE with open right hand generally at graphic]?

P: Um. I think that the diagrams of the lines where they lead to are pretty clear [POINT with left hand fingers at different terminal branch points on right and left side], and then it shows a picture of each animal and the names of it [GESTURE with open left hand generally], so what they are in scientific terms and they are in kinda lay terms.

I: What do you think this picture is trying to show about *Balaenoptera musculus* and *Tursiops truncatus* [POINT to taxa]?

P: Um. They both came originally from a subgroup that also created *Dorudon*. And they are two different groups but they are both whales, and were both, we see them both today.

I: What do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa]?

P: Um, again they came from the same kind of, subgroup [GESTURE with open left hand at area left of *Elomeryx* node] both dating back to the artiodactyl [GESTURE with left hand at Artiodactyl ancestor], but we know that the *Elomeryx* was around 36 million years ago and the hippopotamus is something that we see today.

I: So you think that both *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa] came from the subgroup?

P: Uh, from this same group [GESTURE with left hand finger around Elomeryx node].

I: From this same subgroup [GESTURE with open right hand around *Elomeryx* node]?

P: Yeah, whatever that was.

I: OK.

I: Now, at one time there was one species of animal and now there are hippopotamuses, baleen whales and toothed whales [POINT to taxa]? How do you explain this?

P: [let out breath] Um, evolution and then how animals change according to their environments, and according to nat, natural disasters and things that happen in nature. Depending on what happened in that time frame.

I: And, do you have any idea of how that change happens?

P: Um, I know that some of it is natural disasters, I know that some of them, um, occur from the planet's rotation, I know some of them occur from other things that happens in space, but I don't know like specifics [GESTURE with open hands generally].

I: OK. So, how do animals, how do you think animals change?

P: Um, animals change depending on what they need to do to continue to survive.

I: Now, is there anything else interesting about this graphic that maybe I haven't asked you about, but that you think looks interesting [GESTURE with open right hand palm down generally at graphic]?

P: I think you've covered it.

I: Mm. Now, if you had to tell someone about this graphic, what would you tell them? [GESTURE open right hand generally at graphic].

P: Um. I would tell them that it's, pretty easy to follow, I mean if you follow the lines you can see when the animals were discovered, what time they lived [GESTURE with open left hand generally at graphic], and really what other groups they were evolved from [GESTURE with left hand fingers generally at graphic], and you can definitely see through like the pictures on the right side [POINT with left hand finger at right side of graphic], like you'd never see like how the animals change to become what we know today [GESTURE step-like movement with open left hand palm down three times slightly upwards each time].

I: So, if I asked you, um, to tell someone what you think the role or the purpose of this graphic is, what would you say?

P: I think the purpose is to show, um, evolution and how animals have changed over time from what they originally were to things that we can see everyday, and to show those similarities and the differences [GESTURE with left hand generally at graphic].

I: Mm. That's all the questions I have about this.

Elliot (aged 11); Participant 016 – branched tree

Date: 02/27/2014 Participant #: 016_02272014_1_BR Duration: 8 minutes

I = interviewer; P= participant

I: So my first question is, what do you think this picture is trying to show?

P: Well, I think it's trying to show the evolution of the animals [GESTURE with open right hand generally at graphic], like – how it started here [POINT with right hand finger at Artiodactyl ancestor] and then it just kept on going through the years [GESTURE with open hands palms up moving up each side of graphic]. Like, these were from farther back [GESTURE with open right hand generally at bottom of graphic] and these just started – evolving kind of what to we know today [POINT with right hand finger at extinct right taxa and up right branch].

I: How do you think that happened [GESTURE with open right hand generally at graphic]?

P: Well, I definitely – I'm not sure, but I, [laughs] I really don't know. I just think something happened that could cause of all that. Like some, I, I don't know. [laughs]

I: OK. Well, you think. You think that these [GESTURE with open right hand at right side of graphic] look different from these [GESTURE with open right hand at bottom of graphic] and so you think that they've changed?

P: I definitely think that they've changed.

I: Do you have [stops when participant begins to speak] Sorry, go ahead.

P: They just kinda look similar then they just start to merge into the different animal [GESTURE with open right hand palms up generally at graphic, then bring hands together, then rolling movement of right hand].

I: OK. So you think they change, and how do you think that change might happen?

P: Uh.

I: How do you think that kind of change happens?

P: Huh [laughs]. I really don't know.

I: OK.

I: What kinds of things do you see shown here [GESTURE with open right hand generally at graphic]?

P: Like I said, I definitely think that it shows the animals from farther down – in the years [GESTURE with open right hand generally at graphic at bottom, then top left side] until they get, just – e, more evolved. So, um – yeah I guess.

I: They get more evolved.

P: Mm-hmm.

I: OK.

I: What do you think this picture is trying to show about *Balaenoptera musculus* and *Tursiops truncatus* [POINT to taxa]?

P: I think that it's trying to show you, about just kinda their ancestors and how they used to be, and just kind of to show you – just how they were made [GESTURE hands loosely clasped and then open hands gestures generally].

I: OK. So you think this is trying to show you [POINT with right hand fingers at baleen whale, then toothed whale], um, what their ancestors used to be like [GESTURE with open right hand down along right branch],

P: Mm-hmm.

I: or what they used to look like [POINT with right hand fingers at baleen whale, then toothed whale]?

P: I – what their ancestors and what they [emphasis] used to look like [GESTURE hands clasped and then right hand gestures generally].

I: OK.

I: What do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa]?

P: I think it's trying to show you that there weren't very many – just versions of that animal before it came to the hippopotamus [GESTURE with open left hand palm up upward along left side of graphic].

I: Not very many versions?

P: No, not really. I mean, like, you, look at all these whales [emphasis] and there's a bunch of them [POINT with right hand fingers generally at taxa on right branch]. And then you look at this and there's only a few ancestors [POINT with open right hand at *Elomeryx* and Artiodactyl ancestor].

I: And so you think the ancestors are versions of these ones [GESTURE with open right hand at graphic]?

P: [nods]

I: Now, at one time there was one species of animal and now there are hippopotamuses, baleen whales and toothed whales [POINT to taxa]? How would you explain this to somebody?

P: I would say that this is how it started [POINT with right hand fingers at Artiodactyl ancestor] and then just over periods of times, environments started to change [GESTURE with open right hand generally at bottom of graphic] which means they had to adapt to different things [GESTURE with open right hand generally at graphic]. Then as they –

had children, then they had to evolve differently [GESTURE with right hand generally at right side branch] and that just kept going on and on until you get something completely different [GESTURE with right hand at top of graphic].

I: Mm. Is there anything else that you think interesting about this graphic [GESTURE with open right hand palm down generally at graphic]?

P: I think it’s interesting that it definitely, makes it clear. It’s just kind of right out there [GESTURE with both hands generally at graphic] and there’s not like, a bunch of side captions [POINT right hand finger at various points near top of graphic], and it’s just kind of focused on the main idea [GESTURE with both hands generally at graphic].

I: OK.

P: Not all these other examples [GESTURE with right hand generally at graphic].

I: And what do you think that main idea is?

P: The main idea is its’ supposed to show you how the animals were made, just how they adapt, and you know just how they are today [rising tone] [GESTURE with right hand generally at graphic].

I: Now, if you had to tell someone about this graphic, so if I invited someone in and said “Can you tell them what, this graphic is trying to show”, what would you tell them? [GESTURE with open right hand generally at graphic].

P: I would say, OK, so this is how this animal [POINT with right hand finger at Artiodactyl ancestor] was and then it created two new species [TRACE with open right hand from Artiodactyl ancestor up left branch to *Elomeryx*], this one [POINT with right hand finger at *Elomeryx*] and that one [POINT right hand finger at *Pakicetus*], and but over periods of times the environment began to change, so when they had children [GESTURE with open right hand at right lower branch] and just like I said [laughs] the environments had changed, and they would have children they would have to evolve [GESTURE with right hand finger generally at right branch], and just, you know, just, that.

I: So this one [POINT with right hand finger at Artiodactyl ancestor] had to change?

P: Mm-hmm. It had to change.

I: And then it had children [POINT with right hand finger at Artiodactyl ancestor], and then those children had to change [GESTURE rolling movement with right hand finger]?

P: Well, not necessarily their children, just like over a long [emphasis], just years of that animal [GESTURE with both hands generally].

I: So over a long time?

P: Yes.

I: OK. So not just their children, but lots of their children?

P: Well, their children's children [GESTURE with both hands generally], I mean [pause]

I: OK.

P: Like this race existed for a million years [GESTURE towards me with open hands spread apart palms facing, and circular movement of right hand during word 'years'], then this race existed [GESTURE as above but hands moved step-like to right], then that race existed [GESTURE as above and hands moved step-like to right].

I: So one – race or group [GESTURE downward with open right hand palm down], another race or group [GESTURE downward with open right hand palm down],

P: Yes.

I: And then another one [GESTURE downward with open right hand palm down]?

I: How would describe the connection between these ones [POINT with right hand finger at *Pakicetus*, then *Rodhocetus*, then *Dorudon*] and whales that are alive today [POINT at baleen whale]?

P: Well the connection is just basically, you can see that they used to have shorter legs and fins [POINT with open right hand at *Pakicetus* area], and then they grew longer [emphasis] legs and fins, and had more of a bigger body [POINT with open right hand at *Pakicetus* area]. And you have this one [POINT with right hand finger at *Dorudon*] that barely has back legs, but it has huge front fins, it definitely seems to be a lot bigger [POINT with right hand finger at *Dorudon*], and then you have the whale that we have today that is huge and has just fins – and it's bigger [POINT with finger and open right hand at whales].

I: OK. And what do you think the connection is between *Elomeryx* and hippopotamus [POINT with right hand finger at taxa]?

P: Well you can definitely tell that they're related cause, I mean, the ears are the same, the eyes are the same [POINT with right hand finger at hippo, then *Elomeryx*, then area around node], but definitely the hippopotamus is a lot heavier [POINT with finger at hippo]

I: OK.

P: than the *Elomeryx* [POINT with finger at *Elomeryx*]. And they definitely have shorter feet [POINT with open right hand at hippo], and I mean, they are definitely connected [GESTURE with open right hand between taxa], but this seems like an early, definitely seems like an earlier stage [POINT with open right hand at *Elomeryx*] of the hippopotamus [POINT with open right hand at hippo].

I: An early stage?

I: So you think they're related because this one [POINT with right hand finger at *Elomeryx*] is an early stage of that one [POINT with right hand finger at hippo]?

P: Mm-hmm.

I: Just one more question. What do you think these, what do you think that, is trying to show [POINT with right hand finger at *Elomeryx* node, then *Dorudon* node, then *Elomeryx* node]?

P: I think that, it's trying to show you how longer, there were years [POINT open right hand at root]. I mean like this took millions of years [TRACE with right hand finger from root to *Elomery*x node], this only took like a few million years [TRACE from root up right to *Pakicetu*s, then *Pakicetus* node, then *Rodhocetus* node], and then that [TRACE from *Rodhocetus* node to *Dorudon* node]. Then it got a little bit bigger here [TRACE from *Dorudon* node to whale node]. I mean, it's going from – 55 to 36 [POINT with right hand finger at 55 million years ago, then 36 million years ago] which means it's got longer [TRACE with right hand finger from 55 million up left branch], and this one's going from 55 to 48 [POINT at right hand finger at 55 million, then around 48 million year line around *Rodhocetus* node area] so it's definitely a lot shorter [POINT with right hand finger at 55 million, then around 48 million year line around *Rodhocetus* node area]. And then there's 48 to 47 [TRACE with right hand finger from *Rodhocetus* node to *Dorudon* node], which is definitely shorter.

I: OK, so you think it's showing you the time when certain things happened – and the thing that happened is?

P: That just the environment's changed, probably, or there was some kind of effect that made them adapt to something new.

I: I guess just one more. Is there anything else that you want to tell me about this, that maybe I haven't asked you about?

[exchange in which she suggests adding a colorful border to grab people's attention to try and get little kids interested in it]

P: And maybe try to add like another animal or something – and like have more of this graph next to each other but with different animals to show how all the, all the animals evolved in general [GESTURE with open hands generally at graphic].

I: So maybe show how other animals are related to these animals?

P: Yes.

I: OK. That's all the questions I have.

Michael (aged 11); Participant 017 – linear tree

Date: 04/07/2014 Participant #: 017_04072014_1_L Duration: 5 minutes, 30 seconds

I = interviewer; P= participant

I: So my first question is, what do you think this picture is trying to show?

P: Uh. The – evolution – through the specific breeds. Um. Um, some of the changes [rising tone].

I: And how do you think that happened [GESTURE with open right hand generally at graphic]?

P: Um. The environment changed so they had to – evolve – and g – and gain, features to help them in that environment.

I: OK. So, what kinds of things do you see here [GESTURE with open right hand generally at graphic]?

[exchange offering to move graphic if he would prefer to sit]

So, what kinds of things do you see shown here?

P: Um. Amphibians? Well – hmm.

I: Well, what do you think maybe are amphibians?

P: Uh. Aquatic animals that can go in and out.

I: OK. So – amphibious. Animals that go into the water as well as live on land [GESTURE with open right hand generally at graphic]. So you see animals that are, that do both [GESTURE open right hand generally at graphic].

I: OK. Is there anything else that you see?

P: Um. Not. Mm-mmm.

I: OK. Now, what do you think this picture is trying to show about *Balaenoptera musculus* and *Tursiops truncatus* [POINT to taxa]?

P: Um. How they were divided into a different species [GESTURE with right hand finger in air].

I: Now, what do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa]?

P: That the *Elomeryx* may be the ancestor of the *Hippopotamus*?

I: Now, at one time there was one species of animal and now there are hippopotamuses, baleen whales and toothed whales [POINT to taxa]? How would you explain this?

P: Hm. [pause] Hm. Um. There was a group of animals [GESTURE with open hand generally at graphic] that at one point split off, went into, farther upland and farther into, the sea and they ended up evolving into creature like that [POINT with right hand finger at whales] and then that [POINT at hippo].

I: OK. Is there anything else interesting about this graphic? Maybe something that I haven't asked you about?

P: Uh. Hm. It shows the timeline for each of the animals [GESTURE with open left hand up left side of graphic].

I: OK, so when they lived?

P: Yeah.

I: Now, if you had to tell someone about this graphic, so if I invited someone in here and I said "Can you tell them what this graphic about", what would you tell them? [GESTURE with open right hand generally at graphic].

P: It's the evolution through a species, and where – at one point, one group got split off from a. Well [pause] um, one group [GESTURE with open hand at bottom of graphic] chose a different – environment and then the other one chose, uh, maybe the opposite environment or.

I: OK, so you think that one group – and you think this is the group [POINT with open right hand at Artiodactyl ancestor]? Or do you think something else is the group?

P: The group of the ancestor [POINT with right hand fingers at Artiodactyl ancestor], uh.

I: Hm-hmm.

P: One travelled off into the sea [TRACE with right hand finger up right side of tree], then one travelled off to the land [TRACE with right hand finger up left side of tree].

I: And you think they chose to do that?

P: Mm-hmm. [pause] Well – may, maybe there was some sort of natural disaster, but mostly likely they would have chose it.

I: OK. Now can I ask you, what do you think this – point represents or shows [POINT with right hand and finger in circles around *Dorudon* node]?

P: [pause] Um. [pause] Uh. [pause] How – over time some of the species may end up losing [rising tone] some of the [pause] [POINT with right hand finger at upper right of graphic] – well the flipper on this [POINT with left hand fingers at *Dorudon*] are a little more like hands, so – it's possible it could have been able to go farther up instead of, and with the baleen whales they'll just end up getting beached and [GESTURE with right hand finger at upper right of graphic].

I: OK. So you think this one [POINT right hand finger and counterclockwise circle and *Dorudon* flippers], its flippers are, are different from the other ones that you see. OK. So, do you think that this animal is at this point here [POINT with right hand finger and make counterclockwise circle around *Dorudon* node]?

P: Uh. Yeah.

I: OK. That's all the questions I have about the graphic.

Josh (aged 18); Participant 018 – linear tree

Date: 04/12/2014 Participant #: 018_04122014_2_L Duration: 4 minutes, 30 seconds
I = interviewer; P= participant

I: So my first question is, what do you think this picture is trying to show?

P: Um. The lineage of how [SPLIT open hands open on either side and top of graphic, and move down to bottom and bring hand together] – this uh, Ardo-ido-dactyl like [POINT with open left hand at Artiodactyl ancestor] – the lineage of where it's from I guess [SPLIT use open hands show split on either side of graphic, moved up and down]. Or no, I'm wrong. The other way around – this [POINT with right hand finger at Artiodactyl ancestor, then SPLIT use right thumb and fingers to show split and move up branches] branched out in these directions.

I: OK. So the lineage of these things [GESTURE with right hand finger across taxa at top generally at graphic] – and where they came from?

P: Yes. Yes.

I: And how do you think that happened [GESTURE with open right hand generally at graphic]?

P: Um. I think that this one [POINT with left hand thumb at Artiodactyl ancestor, then TRACE up ~1/3 of left branch] went on the land, and this one [POINT with left hand finger at Artiodactyl ancestor, then TRACE up ~ 1/3 of right branch] went towards the water, and evolution just kind of – went about it's way [SPLIT use open hands to show split and move up each branch while rotating wrists slightly at Artiodactyl ancestor].

I: Now what kinds of things do you see shown here [GESTURE with open right hand generally at graphic]?

P: Just in general?

I: Mm-hmm. Anything that stands out to you.

P: Well – uh, uh – specially the pictures of the different [POINT with open left hand at extinct taxa on right branch, then POINT with left hand at extinct taxa], um – animals I guess along the lineage [GESTURE step-like movement with left hand held flat around the three extinct taxa on right branch] – uh, and then of course the dotted line [SPLIT use open hands to show split and move up left and right branches] that kind of keeps everything together.

I: OK. And so.

P: And like the fact the one's blacked out because [POINT with left hand finger at Artiodactyl ancestor, then TRACE with left hand up right branch].

I: Well, what do you think that means? What do you think?

P: Well that's the starting point [POINT with left hand fingers at Artiodactyl ancestor], but I did not get that at first.

I: So you think that reflects the starting point because it's blacked out [POINT with right hand at Artiodactyl ancestor]?

P: Yes.

I: And these animals along the lineage [POINT with right hand finger along right branch, up and down twice, then back up], how do you think they fit into the story?

P: This [POINT with left hand finger at Artiodactyl ancestor] evolved into those [TRACE with left hand finger along right branch] – slowly over time [GESTURE with open hand generally at graphic].

I: OK. Now, what do you think this picture is trying to show about *Balaenoptera musculus* and *Tursiops truncatus* [POINT to taxa]?

P: That they are related. Similar to how we are related to monkeys – or you know primates, I guess [GESTURE with open hands generally towards me].

I: And, what do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa]?

P: The *Elomeryx* evolved into the hippopotamus, *Hippopotamus amphibius* [POINT with left hand at left branch].

I: Now, at one time there was one species of animal and now there are hippopotamuses, baleen whales and toothed whales [POINT to taxa]? How do you explain this?

P: Um. Similar to how some species on Madagascar went in a completely different direction that species in other parts of the world, you know, went in a different direction. It all depends on where they were, and on what point in time and how evolution just kind of – works [GESTURE open hand generally not directly at graphic]. Like these [POINT with left hand at Artiodactyl ancestor, then TRACE branch to *Pakicetus*] it looks like they went towards water, and these not necessarily [POINT with left hand at Artiodactyl ancestor, then TRACE branch to *Elomeryx*].

I: So where they were in terms of what the environment was like?

P: Mm-hmm, and then what that called for from them to say alive.

I: OK. Is there anything else interesting about this graphic? Maybe something that I haven't asked you about?

P: I do like the fact that this says at what point in time these things were around [POINT with left hand at time labels on left of graphic], and I guess that should have been a better indicator of where to start because of up here says today [POINT with left hand at 'Today'].

P: OK. So it helped to have the timeline to know which was today and which was in the past?

I: Yes, most definitely. And, and it gives more information as well. Um, yeah.

I: Now, if you had to tell someone about this graphic, so if I invited someone in and I said "Can you tell them what this is all about", what would you say? [GESTURE with open right hand generally at graphic].

P: Um. I would say this shows [GESTURE with both hands generally at graphic], this demonstrates both evolution and the ancestry of the hippopotamus, the baleen whales and the toothed whales [POINT with left hand at *Hippopotamus amphibius*, *Balaenoptera musculus*, then *Tursiops truncatus*], and how, um, evolution [SPLIT use both hands up to split from bottom of graphic], and I would probably use this to explain how evolution works.

I: And how would you use that. [pause] So, you said that you could use to explain how evolution works, what would you tell them.

P: In some way, just to kind of explain [POINT with both hands at bottom of graphic]. I mean, I would need more to explain it – but like how you know some of this animal went in this direction and some of this animal went in this direction [POINT with both hands at Artiodactyl ancestor, then TRACE up left branch with left hand to *Elomeryx*, and up right branch with right hand to *Dorudon*] and I could compare that to how everyone thinks that we directly evolved from monkeys and that's not true [GESTURE with both hands generally towards me] – you know, that we're just on the same branch of the same tree [SPLIT use both hands to show split movement from bottom of graphic up left and right branches] – I guess. And depending on where the animals were they could have evolved in completely different ways [GESTURE with both hands on either side of graphic].

I: Perfect. That's all the questions I have about the large graphic.

Daniel (aged 15); Participant 019 – branched tree

Date: 04/12/2014 Participant #: 019_04122014_2_BR Duration: 4 minutes, 35 seconds

I = interviewer; P= participant

I: So my first question is, what do you think this picture is trying to show?

P: It's trying to show all these different animals have come from this one ancestor [POINT with right hand fingers at *Elomeryx*, then hippo, then whales, then taxa on right branch, then Artiodactyl ancestor].

I: And how do you think that happened [GESTURE with open right hand generally at graphic]?

P: Uh, through different types of evolution. Like, uh, there's geographic isolation and all of the different types of, uh, natural selection.

I: OK. Now what kinds of things do you see shown in this graphic [GESTURE with open right hand generally at graphic]?

P: Um, I can see how – uh, like this branch [POINT with right hand finger at *Elomeryx*] it moves and it becomes more of like [TRACE with right hand finger from Artiodactyl ancestor to *Elomeryx*], I'll say wolf-like, like it has legs. And over here it turns more to the marine side [POINT with right hand finger at right branch of graphic], it goes to swim more instead of walk.

I: Now, what do you think this picture is trying to show about *Balaenoptera musculus* and *Tursiops truncatus* [POINT to taxa]?

P: It's trying to say that like – even though they look kind of the same but they are also very different [POINT and COMPARE terminal taxa with right hand finger and thumb], they both come from the same family [POINT with first two right hand fingers towards bottom of graphic].

I: Now, what do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa]?

P: It's trying to show that they are far apart in like time wise [POINT with right hand finger and move between *Elomeryx* and hippo several times], but again they come from the same family even though the do look very different [GESTURE with right hand generally at graphic].

I: Now, at one time there was one species of animal and now there are hippopotamuses, baleen whales and toothed whales [POINT to taxa]? How do you explain this?

P: Um. Like I said before evolution, uh, can happen to try to – uh, make them better, I guess [GESTURE with right hand generally at graphic]. Like, like if it wants to get more water food it can turn more into like an aquatic animal [GESTURE with right hand generally, then POINT with finger at Artiodactyl ancestor, then TRACE up right branch to baleen whale, then GESTURE generally at right side of graphic], like over here with the whale. Or it can turn to more like a mammal [POINT with finger at Artiodactyl ancestor, then TRACE up branch to *Elomeryx*, then POINT at and move back and forth between *Elomeryx* and hippo], and turn more, have like legs, so it can get like different foods and predators. [long pause] Yes, even though a whale is a mammal.

I: So it can get these features?

P: Yes. So these features help them survive cause only the best fit – won't die off.

I: And how do you think it gets them?

P: It gets them through, um, natural selection, can help them like evolve I guess. Like, yeah.

I: You mentioned want?

P: Want – like?

I: That they wanted something or?

I: Oh, yeah. Like – like to get better food maybe [GESTURE with right hand generally] they would. Like maybe there's a lot more aquatic animals that they could eat, so they learn to swim more and they develop that so that they could get easier food [GESTURE with right hand generally].

I: OK. Is there anything else that you think is interesting about this graphic? That maybe something that I haven't asked you about?

P: I thought it was actually interesting that you show, like the colors and exactly what they looked like because you don't always get that – looking at fossils.

I: So, the fact that it shows you a lot of detail [GESTURE with right hand generally at graphic].

P: Yeah.

I: About extinct animals?

P: Yeah.

I: Now, if you had to tell someone about this graphic, so if I invited someone in and I said "Can you explain what this is about to them", what would you say? [GESTURE with open right hand generally at graphic].

P: I would say like all these animals [GESTURE with right hand at terminal taxa from left to right] have branched off from this one animal [POINT with finger at Artiodactyl ancestor] down here from 55 million years ago [POINT with finger at Artiodactyl ancestor], and they have all changed to better themselves [GESTURE with right hand generally at graphic], and they're all closely related [GESTURE with finger generally at graphic], even though you might not think a hippopotamus and a whale are very close [GESTURE with right hand towards terminal taxa].

I: And just one more question. What do you think – that these points [POINT with right hand finger at nodes for *Dorudon*, then *Rodhocetus*, then *Dorudon*, then whales, then *Elomeryx*/hippo] are trying to show?

P: Those points are showing, uh, the branches – so at this point [POINT with right hand finger at Artiodactyl ancestor], this animal got all the way to here [TRACE from Artiodactyl ancestor to *Elomeryx*/hippo node], and then something happened [SPLIT use fingers to show split at *Elomeryx*/hippo node, then TRACE up each branch simultaneously] that would make them branch off [SPLIT use fingers to show split at *Elomeryx*/hippo node, then TRACE up each branch simultaneously] and wanted to look, turn more into like a hippopotamus kind [TRACE with right hand from *Elomeryx*/hippo node to *Hippopotamus amphibius*] and one to look more wolf-like [TRACE with right hand from *Elomeryx*/hippo node to *Elomeryx*].

I: That's all the questions I have about this.

Abby (aged 13); Participant 020 – branched tree

Date: 04/12/2014 Participant #: 020_04122014_2_BR Duration: 5 minutes, 10 seconds

I = interviewer; P= participant

I: So my first question is, what do you think this picture is trying to show?

P: How – all these animals branched off from here [GESTURE with right hand finger at taxa on left side, then bottom, then taxa on right side, then bottom].

I: OK. [pause] And how do you think that happened [GESTURE with open right hand generally towards graphic]?

P: Evolution [rising tone].

I: Now what kinds of things do you see shown in this picture [GESTURE with open right hand generally at graphic]?

P: Um. [pause] The animals [GESTURE with right hand finger generally and at taxa on left side of graphic], and like you see – branches [TRACE shape of branches around *Rodhocetus* (node and either side of branch) and *Dorudon* (node and either side of branch)], and it splits off [SPLIT use hands held flat to show split into left and right branches from bottom of graphic] and its goes two different ways. And it looks like, this is more like sea [GESTURE with open right hand at right side of graphic], and this more like land animals [GESTURE with open right hand at left side of graphic].

I: OK. So you see animals on different braches, and land versus sea animals?

P: Mm-hmm. [pause] And these were here a long time ago [GESTURE with right hand finger back and forth across graphic at level of 36 million years ago] and these are ones we see today [GESTURE with right hand finger back and forth at level of terminal taxa].

I: What do you think this picture is trying to show about *Balaenoptera musculus* and

Tursiops truncatus [POINT to taxa]?

P: About their ancestors [POINT with right hand finger at Artiodactyl ancestor]. And, when this one branched [pause]. And [pause] um [pause] show you how they evolved from this [POINT with right hand finger at Artiodactyl ancestor, then extinct taxa on right] to how they are today [POINT with right hand finger at *Balaenoptera musculus*].

I: OK. What do you think this picture is trying to show you about *Elomeryx* and *Hippopotamus amphibius* [POINT to taxa]?

P: Um. This is its ancestor [TRACE with right hand finger from *Elomeryx* along branch to *Elomeryx*/hippo node and to hippo, then to *Elomeryx*] [pause] [GESTURE between Artiodactyl ancestor, then *Elomeryx* and back].

I: You think. Something is one's ancestor?

P: Mm-hmm.

I: Which do you think is the ancestor?

P: This [POINT with right hand finger to *Elomeryx*, then Artiodactyl ancestor, then hippo] and here [indistinct].

I: These ones? You think these both [POINT with right hand finger *Elomeryx*, then Artiodactyl ancestor, then *Elomeryx*, then Artiodactyl ancestor] are the ancestors of that one [POINT with right hand finger at hippo]?

P: Well this [POINT at *Elomeryx*, then Artiodactyl ancestor] is the ancestor of this one [*Elomeryx*]? And then it goes to that [TRACE from *Elomeryx* along branch to *Elomeryx*/hippo node, then POINT at hippo].

I: OK. So you think that's [POINT with right hand finger at Artiodactyl ancestor] the ancestor

P: Or [GESTURE right hand finger at graphic]. [speaking at the same time]

I: of that one [POINT right hand finger at *Elomeryx*] or?

P: Or, like this is the ancestor [POINT at *Elomeryx*/hippo node], and then this branches off this one [TRACE from node to *Elomeryx*], this branches off this one [TRACE from *Elomeryx*/hippo node to hippo].

I: So, you think this [Artiodactyl ancestor] is the ancestor of this [POINT with right hand finger and circular movement around node]?

P: Mm-hmm.

I: What do you think this [POINT right and finger circular movement around node] is?

P: Uh. [pause] I don't really know.

I: Do you think – what do you think these points [POINT with right hand finger *Elomeryx*/hippo node, then baleen and toothed whales node, then *Dorudon* node, then *Rodhocetus* node] – do you think these are trying to show anything – or not?

P: Um. [long pause] They have like a time and a new, branch that starts and then [trails off].

I: Now, at one time there was one species of animal and now there are hippopotamuses, baleen whales and toothed whales [POINT to taxa]? How do you explain this?

P: This [POINT with right hand finger at Artiodactyl ancestor] slowly evolved into all of these [TRACE with right hand finger from Artiodactyl ancestor node to *Elomeryx*/hippo node, then along branch to *Elomeryx*, then from *Elomeryx*/hippo node to hippo, then POINT at extinct taxa on right], which then became these [POINT with right hand finger at baleen and toothed whales].

I: OK. [pause] Is there anything else that you think is interesting about this graphic? Maybe something that I haven't asked you about, but that you think is interesting or maybe looks important?

P: Um. [pause] These – look a lot similar [POINT with right hand finger at Elomeryx, then Artiodactyl ancestor, then POINT at Artiodactyl ancestor and *Elomeryx* with thumb finger] and then how, it really does like slowly look like it turned into a whale [POINT with right hand finger generally at extinct then extant taxa on right].

I: So you think that the Artiodactyl ancestor looks very similar, to *Elomeryx* [POINT with at Artiodactyl ancestor then *Elomeryx*], but this, um, looks like it's more, happened more slowly [GESTURE open right hand up right side of graphic, and at terminal taxa on right]?

P: Mm-hmm. It had a lot more different animals [GESTURE with right hand finger up right side of graphic], and it slowly evolved [GESTURE with right hand finger up right side of graphic] into each of these different ones [GESTURE with right hand finger up right side of graphic].

I: Now, if you had to tell someone about this graphic, so I invited someone in that, that's here at the museum and I said "Tell them what this is all about", what would you tell them? [GESTURE open right hand generally at graphic].

P: It's all about, evolution, and how this [POINT with open right hand at Artiodactyl ancestor] – turned into these [TRACE with right and left fingers up either graphic and curved, then POINT at terminal taxa]. About how, um, the animals we see today what they were like millions of years ago.

I: OK.

P: And – this could represent time [POINT with right hand finger at *Elomeryx*/hippo node, then *Dorudon* node], a time period.

I: OK. That's all the questions I have about the graphic.