Interpretation, invention, and interaction: Using students (mis)understandings to redesign the Tree of Life

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This series of projects investigates undergraduate students' understanding of phylogenetic relatedness in how they interpret its standard cladogram representation, to the diagrams they invent to solve problems of relatedness, to the possibilities of interactive design for supporting their learning to use the expert diagram. The overarching goal across these studies is to seek new approaches to teaching standard scientific representations; approaches that leverage the affordances of multimedia and the notion of pedagogical representations to scaffold the transition from novice to expert understanding of challenging scientific representations.

Countering diagrammatic narratives

The errors students make when reasoning with cladograms are well-documented in prior research (Gregory, 2008; Halverson, Pires, & Abell, 2008; Meir, Perry, Herron, & Kingsolver, 2007). In this project, we seek to understand why and how these misreadings occur. The process of interpretation, we posit, involves an interaction between semiotic, perceptual, and prior knowledge assumptions on the part of the viewer. In 159 individual interviews, undergraduate students viewed one of four different presentations of the same cladogram, of which they were asked to interpret various structural elements, and to reason about the relationships depicted.

All students were at least aware of the misconceived folk theory of evolution, in which a simple, primitive ancestor gradually transforms into a more sophisticated and complex mammal. We observed that the visual structure of the cladogram cued interpretations based in a folk theory of evolution. That is, students would map narrative themes from this folk theory – such as characters, events, and progress – onto the structural elements of the cladogram, such that the early primitive beginning was associated with the bottom left of the diagram, and the modern sophisticated endpoint was associated with the upper right. This interpretation was observed in three of the four different presentation conditions. However, with students shown an animated diagram revealed from the top toward the bottom, we observed these spatial metaphors to be reversed. For these students, the upper right was associated with a primitive beginning, and the lower left with a sophisticated endpoint.

Our findings demonstrate the powerful effect of visual design on interpretation: That a change as simple as an animated wipe can reverse otherwise intuitive spatial metaphors. However, they also demonstrate the persistent effect of narrative, and the familiar folk theory of evolution as a frame of perception in the understanding of evolutionary representations.

Inventing an intuitive representation of relatedness

Given that the representational system of cladograms is so difficult for novices to comprehend, we sought to find whether there are more intuitive ways of graphically depicting phylogenetic relationships. In 24 individual interviews, we asked undergraduate students to invent representations to depict the relationships between a group of children with shared toys, or between a group of animals with shared morphological traits. They were asked to explain their invented representations, and then to make sense of a standard cladogram of the same data.

Our data show two distinct manners in which students represented and reasoned about relatedness. These were furthermore significantly associated with the content matter students were led to believe of the invention task and of the standard diagram they later viewed. The *Evo* students, who read the task in terms of species relationships, tended to produce *Mapping* diagrams. *Mapping* diagrams were characterized by their use of locations in graphic space to metaphorically convey meaning, such as of relative numbers of traits, axes of time, and so forth. They tended to include representational forms typically encountered in formal schooling, such as graphs, tables, and charts. Meanwhile, the *Toy* students, who read the task in terms of social relationships, tended to produce *Grouping* diagrams. Examples of these are network and Venn diagrams, which use connecting lines or enclosing circles to convey relationships through category membership. Although not statistically significant, the data suggest that *Toy* students reasoned more accurately with the standard cladogram than *Evo* students. They were generally more able to perceive clades – the meaningful perceptual unit with which experts reason about relatedness. Meanwhile, *Evo* students' errors significantly hinged on the spatial metaphors inherent in the diagrams they invented.

These findings illustrate the connection between representational form and reasoning in problems of phylogenetic relatedness. They suggest that the manner in which the problem is conceived frames both the forms of representations, as well as the approaches to interpreting and reasoning with those representations. This study furthermore raises interesting questions to pursue in designing an effective instructional sequence. For example, should learners first become familiar with the cladogram's structure with content less loaded than evolution? Should instruction in cladograms first involve inventing a personally meaningful representation of relatedness? And from those invented representations, do we find a diagrammatic form more intuitive than the standard one, which might be used to bridge the gap between novice and expert understanding (Roschelle, 1996)?

Designs for an interactive multimedia Tree of Life

As our research thus far indicates, a major hurdle to understanding the representational system of the cladogram is its confinement within a flat, two-dimensional space. Frozen on the page, novice viewers can only assume the conventions for reading other kinds of static diagrams. Consequently, they fail to realize the three-dimensional structure of the cladogram. In response, we are developing an interactive computer application that will allow learners to build, manipulate, and compare phylogenetic representations. Versions of this application will be tailored for use by teachers conducting interactive classroom demonstrations; for educational games delivered on websites, iPhones, and iPads; and for interactive displays in evolution-themed museum exhibits. Our design is motivated by a number of principles. One is that removing viewers from the perceptual conventions of 2D representations will help override diagrammatic cues to a folk theory-based interpretation. Another is that facilitating understanding through multiple representations (Ainsworth, 2006), and encouraging the construction of personally meaningful representations (Edens & Potter, 2001; Gobert & Clement, 1999; Kiili, 2003; Papert & Harel, 1991), will facilitate learners' sense-making of the standard scientific representation.

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