Tree-thinking Research in Evolution Education (TREE)

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Despite the centrality of tree-thinking to the structure and growth of biological knowledge, very little is known about the barriers to, and benefits of, students' understanding biological phenomena within a phylogenetic framework. The project involves a grassroots (a.k.a. currently unfunded) community of teaching specialist, scientists, and education researchers who are working to make tree-thinking a central feature of introductory biology education. The various projects and activities can be organized into three broad areas:

I. *Supporting the use of tree-thinking as a coherent theme throughout an introductory biology curriculum.*
II. *Characterizing students' understanding of tree-thinking.*
III. *Studying how an understanding of tree-thinking develops through engagement with disciplinary problem solving.*

Supporting the use of tree-thinking as a coherent theme throughout an introductory biology curriculum

The long-standing promise of phylogeny as a unifying context for coordinating biological knowledge is now being realized in basic and applied research. Patterns of unity and diversity can be viewed through the lens of descent from common ancestry and phylogenetic trees are the "language" for describing these genealogical relationships. While often implicitly adopted by biologists, understanding the structure of the tree of life provides a 'comparative and predictive framework' that cuts across biological sub-disciplines and has the potential to dramatically extend our understanding of the living world. Evolutionary biologists use tree-thinking to reason about major patterns of change in the history of life on earth, relationships among taxa, evolution of characters, patterns of co-evolution among interacting species, and links between phenomena in geology and ecology and patterns of diversity within and among taxa. Unfortunately, the insights provided by tree thinking are not widely recognized outside of those specialists who have been trained in evolutionary biology, and are not generally addressed in biology education.

Despite repeated calls to use evolution as an underlying framework for coordinating the diverse material that constitutes biological knowledge, evolution is generally taught as an isolated topic as part of an overstuffed introductory curriculum. Often, the primary instructional focus within an evolution unit is on the natural selection model in combination with a few canonical examples of adaptive change within species. While evolutionary mechanisms are important to understand, the natural selection model has limited explanatory power when looking at broader patterns of diversity should not be conflated with evolutionary theory more broadly.

Products and activities relating to this aspect of the TREE project include:

- Raising awareness about the difficulties non-specialists face interpreting phylogenetic trees [Baum, D. A., S. D. Smith & S. Donovan (2005). The tree thinking challenge. *Science 310*(5750), pp. 979-980.].

- Arguing for more of an emphasis on a phylogenetic perspective when using evolutionary theory as a theme to coordinate introductory biology curricula [Donovan, S. (2005). Teaching the tree of life: Tree thinking and reasoning about change over deep time. *Evolutionary science and society: Educating a new generation*. J. Cracraft and R. Bybee. Colorado Springs, Biological Sciences Curriculum Study: pp. 97-90. Additional manuscript in preparation].
- Developing instructional resources across diverse biological sub-disciplines that demonstrate the role of tree-thinking in biological research [e. g., BEDROCK Problem Spaces, NESCent SELECTION Project, Investigative Cases].

Characterizing students' understanding of tree-thinking

There are a variety of parallel, loosely coordinated efforts to develop, implement, and validate assessment instruments that capture features of tree-thinking. The skills and understandings addressed include:

- Reading, interpreting and comparing different types of tree graphs
- Relating evolutionary concepts to patterns in trees
- Drawing appropriate inferences from information in trees
- Representing character evolution in trees
- Using trees to support narrative historical arguments

Early findings support the generalization that the vast majority of introductory biology students do not understand how information is organized in phylogentic trees, how patterns in trees can be related to other evolutionary concepts, or how phylogenetic information can be used to solve biological problems.

Products and activities relating to this aspect of the TREE project include:

- Preliminary efforts to characterize students' tree reading skills and their ability to relate various biological concepts to phylogenetic trees [Baum & Koopman; Beardsley & DelMonte; Donovan & White; Meir & Herron; all in preparation].
- Tree-thinking Assessments—Basic and Quiz II [Baum, D. A., Smith, S. D., & Donovan, S. S. (2005). Tree-thinking quizzes I and II: Supporting online material for "The tree-thinking challenge". *Science, 310*(5750). http://www.sciencemag.org/cgi/content/full/310/5750/979/DC1].
- Assessing tree thinking and its role in understanding evolution. A poster presented at the National Association of Biology Teachers (NABT) Annual Meeting. Chicago; November 10-13, 2004.

Studying how an understanding of tree-thinking develops through engagement with disciplinary problem solving

This area involves designing, implementing and assessing the impact of instructional units that engage students in disciplinary reasoning around the construction and interpretation of phylogenetic trees. Emphasizing the integration of declarative and procedural knowledge about science is not new — educational theorists have long critiqued instruction that focuses exclusively on "cultural accomplishments" (Dewey, 1916), "a rhetoric of conclusions" (Schwab, 1962) and "ready made science" (Latour, 1987). Experience with the habits of thinking that are valued and used in a discipline may support a deeper understand of science concepts but there are few empirical studies that look at the relationship between disciplinary reasoning and future learning in science. This is particularly challenging in evolutionary biology because much of the disciplinary reasoning is not well understood by non-specialists and there are few educational models built to support evolutionary problem solving (Rudolph & Stewart, 1998).

Work in statistics (Schwartz & Martin, 2004) and psychology (Schwartz & Bransford, 1998) learning has shown that familiarity with the disciplinary context of knowledge supports subsequent learning from lectures and written materials. A variety of engagement strategies including student invention of solutions and the analysis of contrasting phenomena rich cases have been shown to be effective when they explicitly promote the use of disciplinary norms for evaluating understanding. Thus, this work seeks to explore how experience with disciplinary reasoning in phylogenetics impacts future learning of evolutionary concepts and the adoption of a tree thinking perspective for solving novel biological problems. More specifically, do students who engage in activities that require the invention of systems to organize biological data learn more efficiently from subsequent didactic instruction in phylogenetics? How does a students' understanding of a phylognetic perspective develop over time and transfer across diverse biological phenomena and problem scenarios?

Products and activities relating to this aspect of the TREE project include:

- Students' representations of biological diversity: Trees and typological thinking in introductory biology. An accepted paper to be presented at the National Association for Research in Science Teaching (NARST) Annual Meeting. San Francisco; April 3-6, 2006.
- Ongoing development and piloting of problem solving tasks.
- Research proposals in various states of review and development.

A few additional references

O'Hara, R. J. (1988). Homage to Clio, or, toward an historical philosophy for evolutionary biology. *Systematic Zoology, 37*, 142–155.

Richards, R. J. (1992). The structure of narrative explanation in history and biology. In M. H. Nitecki & D. V. Nitecki (Eds.), *History and evolution* (pp. 19–53). Albany, NY: State University of New York Press.

Rudolph, J. L., & Stewart, J. (1998). Evolution and the nature of science: On the historical discord and its implications for education. *Journal of Research in Science Teaching, 35*(10), 1069-1089.

Schwartz, D. L. & J. D. Bransford (1998). A time for telling. *Cognition & Instruction 16*(4): pp. 475-522.

Schwartz, D. L. & T. Martin (2004). Inventing to prepare for future learning: The hidden efficiency of encouraging original student production in statistics instruction. *Cognition & Instruction 22*(2): pp. 129-184.