Visualizing the Tree of Life:
Learning Around an Interactive Visualization of Biological Data in Museums

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A central goal of many science museums is to provide hands-on experiences in which visitors learn from exhibit elements and through their interactions with other visitors (Falk & Dierking, 2000; Allen, 2004; Humphrey & Gutwill, 2005; Oppenheimer, 1978). These types of experiences are often characterized by physical engagement with scientific phenomena, open-ended exploration, and carefully designed support for collaboration. However, there are many types of experiences that museums might want to offer in this spirit that go beyond the direct manipulation of physical phenomena (Meisner et al., 2007; Louw & Crowley, 2013). In particular, advances in interactive computer displays coupled with new information visualization techniques have made it possible to offer hands-on experiences in which visitors "touch" and explore large scientific datasets (e.g. Louw & Crowley, 2013; Ma et al., 2012; Roberts et al., 2014; Hinrichs, Schmidt, & Carpendale, 2008). Such exhibits create new opportunities for visitors to engage with authentic computational tools (Louw & Crowley, 2013) while at the same time reflecting the evolving nature of scientific inquiry (Henderson, Cortina, & Wing, 2007). Despite these advantages, however, we know little about how such exhibits support learning.

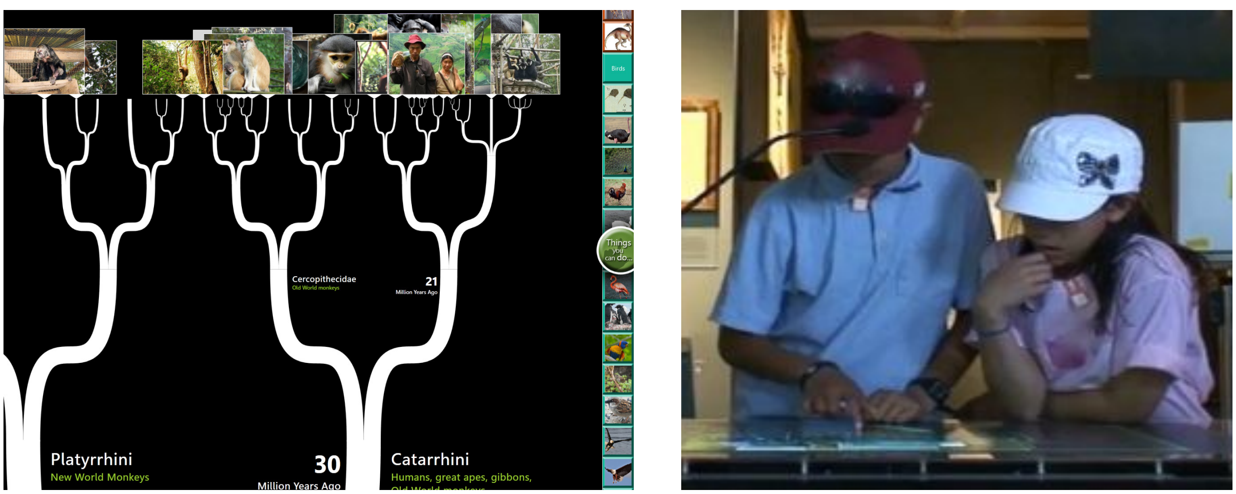

***Figure 1.* Screenshot from DeepTree (left). A dyad interacting with DeepTree on a multi-touch tabletop display at a natural history museum (right).**

The current study investigates visitor learning at an exhibit on the concept that all life is related through common descent. In this study we investigated the effects of social engagement and self-guided interaction on visitor learning around our exhibit. Both of these factors have been shown to play an important role in science museums (Allen, 2002; Crowley & Callanan, 2001; Eberbach & Crowley, 2005; Falk & Dierking, 2000), but we know much less about how they shape learning around computer-based exhibit elements (Meisner et al., 2007), particularly those involving the visualization of large scientific data sets.

We recruited youth dyads, aged 8-15 years, at two well-known natural history museums to participate in one of three conditions[1]. In the first condition, the dyads interacted with our exhibit on a tabletop display for a fixed period of ten minutes. In the second condition, dyads watched a ten-minute video on the same topic. Individual responses on a 53-item post-interview were then compared to responses in a baseline condition. Through this study design we hoped to understand differences in participant interaction between the video and tabletop conditions and whether these differences would lead to improved learning outcomes in the tabletop condition. In particular, we hypothesized that social interaction would be reduced in the video condition and that this, coupled with the self-directed engagement of the tabletop condition, would lead to differential learning outcomes. We collected measures of both social engagement and tabletop interaction through video recordings and computer logs of touch interaction. While our learning objectives and measures concern concepts of evolution, biodiversity, and the tree of life, we believe that our findings can inform the design of other learning experiences that seek to engage the general public in the collaborative exploration of large scientific data sets.

Learning Objectives

Four learning objectives guided both our exhibit design and our learning assessments:

1. All living things are related because they share ancestors in common (NGSS: LS4A)
2. Traits are inherited from shared ancestral lineages (NGSS: LS3A)
3. Tree diagrams show evolutionary relationships and shared traits among groups of organisms
4. Evolution is ongoing

Despite its importance as a central organizing principle of modern biology, studies have repeatedly shown that students and the general public have difficulty understanding evolutionary concepts (see Rosengren, Brem, Evans & Sinatra, 2012). To communicate evolutionary relationships scientists and educators commonly use hierarchical diagrams called phylogenetic trees or cladograms. These diagrams depict shared derived traits and the most recent common ancestors for groups of organisms and are essential elements of modern biology.

Exhibit Design

This study involved an interactive tabletop application called *DeepTree* (Block et al., 2012) that provides a dynamic visualization of evolution and the tree of life (Figure 1). We developed this application through an iterative process of design and evaluation with a team of computer scientists, learning scientists, biologists, and museum curators. *DeepTree* shows the ancestral relationships of 70,000 species starting from the origins of life 3.5 billion years ago. This visualization merges several scientific data sources including the Tree of Life Web Project, the Encyclopedia of Life, the National Center for Biotechnology Information, and the TimeTree knowledge base. The main display area allows visitors to zoom and pan through the entire tree of life. The visualization includes a scrolling image wheel along the right side of the screen containing a subset of 200 species representing important evolutionary groups. When an image is held, the table highlights the species' location in the tree and automatically flies toward it. A final component is a *relate* button centrally located on the image wheel. When pressed visitors can select any two species from the image wheel to trigger the tree to fly to their most recent common ancestor. Once there, the application presents a simplified tree depicting the two species' shared lineage and major evolutionary landmarks. These points can be activated to reveal further information about common ancestors and major traits.

In addition to the DeepTree tabletop condition, we included a second condition in which participants watched a video instead of interacting with DeepTree. The video, *Discovering the*

[1] The full study consisted of four conditions (including two version of the tabletop exhibit). Results from all conditions will be shared in the full paper.

Great Tree of Life, was produced by the Peabody Museum of Natural History (2008) and was chosen for its high production quality and the topics that it covers. The video features animations, voiceovers, and interviews with prominent evolutionary biologists, and covers topics of biodiversity, common descent, phylogenetic trees, evolutionary processes, and the scientific challenge of reconstructing the tree of life. The video addresses all of our learning objectives and includes a dynamic visualization of a growing tree of life as well as a segment that visualizes how changes in a population of organisms can result in speciation over time.

Methods

The current study took place at two locations: the Field Museum in Chicago and the Harvard Museum of Natural History in Cambridge. At each site we recruited groups of visitors with at least one parent or guardian and two youth in the target age range of 8-15 years old. After obtaining informed consent, dyads were randomly assigned to one of the three conditions. After interacting with the tabletop exhibit or viewing the video, researchers individually interviewed each participant. Youth in the baseline condition were interviewed individually immediately after informed consent was obtained. The interview was administered verbally took approximately 20 minutes to compete. Dyads in the exhibit and video conditions were video recorded, and all individual interviews were audio recorded. Dyads were given $15 for participating in the study. Our study was organized around the following research questions:

- RQ1: What are the effects of the tabletop and video exhibits on youth understanding of common descent, the tree of life, and related evolution concepts?
- RQ2: How does social interaction differ between the exhibit and video conditions?

Participants

We invited children to interact in pairs. In total, 248 youth participated in the study (*Mean Age* = 11.56 years; *SD* = 1.68): 129 girls and 119 boys (see Table 2). The mean participant age for each age group did not differ significantly by condition. Parental background (including education level, number of biology courses taken, self-reported religiosity, and acceptance of evolution) also did not significantly differ between conditions.

Conditions

1. [DeepTree] Dyads engaged in a 10.5-minute exploration of DeepTree.
2. [Video] Dyads watched the 10.5-minute *Discovering the Great Tree of Life* video.
3. [Baseline] Participants completed individual interviews.

Results

Learning Outcomes

The learning measures were based on participant responses to 53 open and closed-ended questions in the post-interview. Table 1 shows results for five representative composite measures (the full paper will include results on all measures). First, participants were asked to indicate their agreement (1-5 scale) with five closed-ended questions, each of which conveyed the idea that different kinds of organisms share ancestors (Common Ancestry). For example: “Some kids said that RABBITS and LIZARDS had the same [kind of] ancestor a long, long time ago. Do you disagree or agree with them?” As shown in Table 1, participants in the DeepTree condition were significantly more likely to agree with this measure than were participants in the baseline and video conditions. We also coded participants’ use of tree of life terminology (Tree Terms) in their answers to 10 open-ended questions (e.g., “If a friend from school asked you what the tree of life was all about, what would you say?”). We found that participants in the DeepTree condition were more likely to use terms such as “relate”, “branch”, and “ancestor” than participants in the baseline condition. Likewise, DeepTree participants were more likely to invoke tree of life concepts (Tree Concepts) in their answers to the same 10 questions than baseline participants (96.7% interrater reliability, Kappa=0.681 for the open-ended questions). Participants in the DeepTree condition were also significantly better than baseline participants in interpreting a tree of life graphic, averaged across three closed-ended questions (Tree Accuracy). Finally, we gauged participants' agreement with the idea that evolution is ongoing (Evolution Ongoing) based on the average of their responses to five closed-ended questions and found no significant differences across conditions. There were no significant differences for these measures between the video condition and the baseline condition.

Table 1. Results from post-interview learning outcome measures (*<.05; **<.01)

Learning Measure	DeepTree (DT)	Video (V)	Baseline (B)	Overall Effect	Effect for Tabletop	Effect for Video
Common Ancestry	2.93	2.79	2.48	*F*=3.48*	DT>B, *p*=.027; DT>V, *p*=.023	*ns*
Tree Terms	0.05	0.04	0.02	*F*=5.82**	DT>B, *p*=.002	*ns*
Tree Concepts	0.07	0.05	0.04	*F*=2.89*	DT>B, *p*=.018	*ns*
Tree Accuracy	0.82	0.72	0.67	*F*=3.02*	DT>B, *p*=.025	*ns*
Evolution Ongoing	3.92	3.97	3.86	*ns*	*ns*	*ns*

Social Interaction

We hypothesized that dyads in the tabletop condition would be more likely to interact socially than those in the video conditions. One reason for this is that a multi-touch tabletop interface often requires dyads to negotiate their exploration of the visualization, particularly when they have conflicting goals. In contrast, the voiceover narrative in the video condition would afford fewer opportunities for conversation. To gauge social interaction, we transcribed the video recordings of participant discussion. Due to background noise in the museum environment, the audio was not of sufficient quality to produce a transcript in all cases. In total we transcribed 29 of 31 in the tabletop condition and 27 of 32 in the video condition. When participant voices were not clear enough to transcribe, we used an *inaudible* marker in the transcripts. As an approximation of social interaction, we counted the number of words spoken by both participants. Inaudible segments of speech were counted as one word. On average dyads in the DeepTree condition spoke 434.83 words per session (SD = 285.5), and two dyads did not speak at all. In contrast, dyads in the video condition spoke an average of 6.96 words per session (SD = 14.3). Notably, 20 dyads in the video condition did not speak at all. This analysis confirmed our observations that the dyads in the tabletop interactions were socially engaged in the activity on multiple levels (Davis et al., 2013). The frequency of terms referencing the tabletop content in the dyad conversations was positively related to the Common Ancestry and Tree Accuracy measures (ps < .05). Further analyses of how frequently dyads used DeepTree features such the relate function yielded similar findings and will be reported in the full paper.

Conclusion

These data provide evidence that interactive computer-based exhibits that enable visitors to explore large scientific datasets can be engaging and effective. Contrasting with the baseline condition, visitors who interacted with the DeepTree exhibit were significantly more likely to reason correctly about core evolutionary concepts including common descent, shared ancestry, and the interpretation of a tree-of-life graphic. These gains were seen both in the closed-ended endorsements and the open-ended explanations. Few significant learning gains were seen in the case of the video presentation, although participants' mean scores were often slightly higher than the baseline. This could, in part, be due to the low level of social interaction and self-directed engagement associated with watching a video exhibit in a museum.

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