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Of BATs and APEs: An Interactive Tabletop Game for Natural History Museums

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ABSTRACT
In this paper we describe visitor interaction with an interactive tabletop exhibit on evolution that we designed for use in natural history museums. We video recorded 30 families using the exhibit at the Harvard Museum of Natural History. We also observed an additional 50 social groups interacting with the exhibit without video recording. The goal of this research is to explore ways to develop "successful" interactive tabletop exhibits for museums. To determine criteria for success in this context, we borrow the concept of Active Prolonged Engagement (APE) from the science museum literature. Research on APE sets a high standard for visitor engagement and learning, and it offers a number of useful concepts and measures for research on interactive surfaces in the wild. In this paper we adapt and expand on these measures and apply them to our tabletop exhibit. Our results show that visitor groups collaborated effectively and engaged in focused, on-topic discussion for prolonged periods of time. To understand these results, we analyze visitor conversation at the exhibit. Our analysis suggests that social practices of game play contributed substantially to visitor collaboration and engagement with the exhibit.

Author Keywords
Multi-touch tabletops, interactive surfaces, museums, games, evolution, learning, design

ACM Classification Keywords
H.5.2 [Information Interfaces And Presentation]: User Interfaces - Interaction styles;

General Terms
Design, Human Factors

INTRODUCTION
It is often noted that interactive tabletops seem well suited for use in museums (e.g. [15]). Tabletops can present compelling content in a walk-up-and-use form that ostensibly supports collaborative interaction as visitors gather around the surface. However, although many tabletop exhibits now exist (e.g. [7,15]), few have been rigorously evaluated. On the contrary, tabletop exhibits that we have observed first hand—including some that we have designed ourselves—have consistently fallen short of expectations. Among the shortcomings are shallow engagement [15], poor support for simultaneous interaction, interference between visitors [15,20,25,31], and interfaces that are difficult for visitors to understand and use [15,20]. While many in-the-wild studies of tabletops and interactive surfaces exist (e.g. [2,13,14,15,20,21,25,31]), they tend to emphasize what users do in the wild (e.g. what gestures they use) without focusing on whether or not the designs themselves are successful for their intended purposes (see [2,13] for notable exceptions). Other studies have investigated the potential of tabletops to support

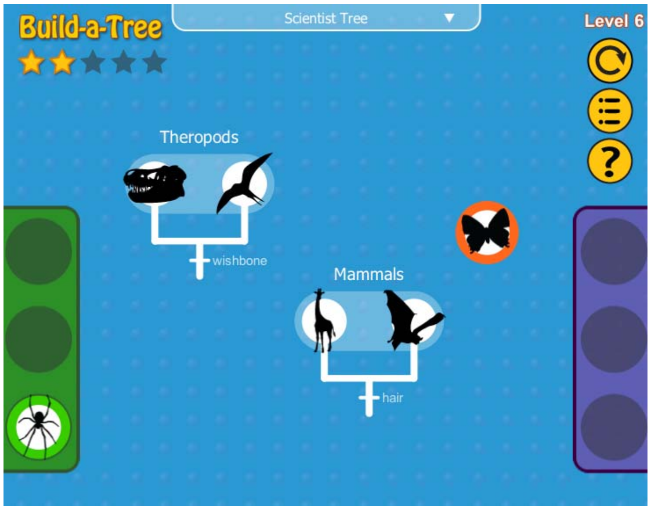

Figure 1. Screenshot of the Build-a-Tree game that we designed for use in natural history museums to help visitors learn about evolution.

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collaboration and learning in more formal environments such as classrooms and laboratories [5,12,17,19,23,24,26-31,33,34]. However, the differences between these settings and free-choice learning environments are substantial, and we cannot assume that success in one context necessarily translates to another.

In this paper, we present results from a study of user interaction with *Build-a-Tree* (BAT), an interactive tabletop exhibit that we designed to help visitors learn about evolution in natural history museums. To evaluate our design, we borrow the notion of Active Prolonged Engagement from the science museum literature [1,9,16]. Active Prolonged Engagement (or APE for short) describes visitor engagement with specific types of interactive science museum exhibits. Among the characteristics of APE are meaningful discussions among social groups, positive collaboration, and prolonged engagement with the phenomenon on display. Through this work we explore ways to achieve APE-like engagement using tabletop technology in the context of a natural history museum.

BACKGROUND

Evolution and Tree Thinking

The broader goal of this project is to help people learn about evolution. In particular, we hope to convey the idea that all life on earth is related through common ancestry. That is, if you go back far enough in time, you can find a common ancestor for any two groups of organisms. One key aspect of this idea is that some types of organisms are more closely related than others. For example, even though bats (order Chiroptera) and owls (order Strigiformes) share superficial features—they both have wings and can fly—bats are more closely related to human beings and other mammals because they share a more recent common ancestor.

In order to communicate hypotheses about the evolutionary history of organisms, biologists use branching diagrams called *phylogenetic trees* or *cladograms* (Figure 2). Such diagrams are essential elements of modern biology [3,8], and scientists and educators have argued for the importance of teaching *tree thinking* skills to the general public [3,4,8]. "Phylogenetic trees are the most direct representation of the principle of common ancestry—the very core of evolutionary theory—and thus they must find a more prominent place in the general public's understanding of evolution" [3, pg. 980]. Examples of tree thinking skills include being able to determine the relative closeness of organisms, reading ancestral traits, and understanding that trees can be rotated around a branching point while remaining structurally equivalent [22]. However, the ability to read and interpret phylogenetic trees has been shown to be difficult for novices, even at the college level [8,22]. Our exhibit attempts to help visitors learn about evolutionary relationships and tree thinking skills.

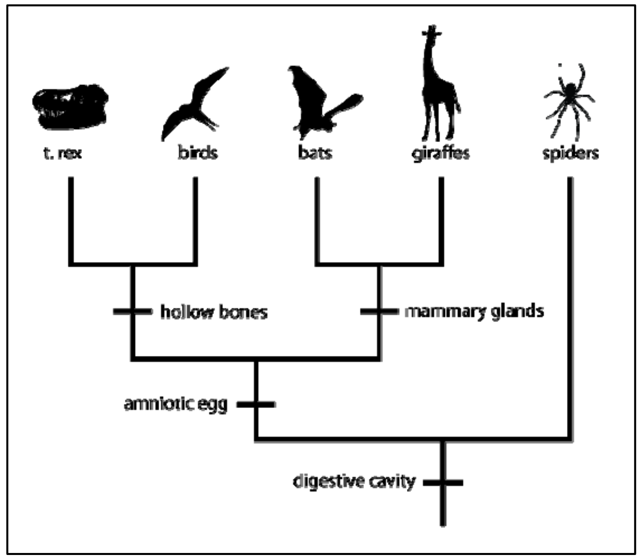

Figure 2. A phylogenetic tree showing evolutionary relationships between five groups of organisms. Shared derived traits (*synapomorphies*) are labeled on the branches.

Active Prolonged Engagement

In the process of designing novel learning environments, it can be difficult to establish baseline criteria to evaluate success. To address this problem, we build on a series of visitor studies conducted at the San Francisco Exploratorium [1,9,16]. These studies develop the concept of Active Prolonged Engagement (APE) to describe visitor experiences with specific types of open-ended interactive exhibits. APE is described in contrast to *planned discovery* (PD) exhibits in which visitors interact with scientific phenomena in a more prescriptive manner (often guided by exhibit labels such as: "To do and notice" and "What's going on?").

> *"The core of the APE exhibit development process was to shift the role of the visitor from that of recipient of instructions and explanations to that of participant. Our goal was to create exhibits where visitors participated, with the museum and with other visitors, in the generation of activities, questions, and explanations related to engaging phenomena."* [16, p. 2]

In addition to prolonged engagement, APE exhibits have been shown to appeal to a wide variety of visitors and to foster open-ended exploration and discovery [16]. Visitors ask qualitatively different types of questions at APE exhibits and tend to use the exhibit to pursue their own answers rather than reading exhibit labels.

Collaboration and Learning with Tabletops

Multi-touch tabletops have been shown to promote physical engagement, reflection, and collaboration in formal learning environments (e.g. [12,26,34]). Researchers have also considered ways to exploit learners' existing social practices and embodied collaborative actions to facilitate

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tabletop interaction [19,24]. This study moves beyond formal learning environments and considers how social practices shape engagement around tabletop exhibits in informal, free-choice learning environments such as museums.

A growing body of work has focused on understanding the use of interactive surfaces in the wild. This includes understanding user gestures; how users approach surfaces in public spaces; transitions between user groups; and interactions between users [14,15,20,25,31]. However, with some exceptions (e.g. [2]), little work has focused on determining whether or not interactive surface designs themselves are successful. Researchers have also pointed out the difficulty of designing for in-the-wild interaction due to the diversity of users and the lack of standard interaction paradigms [14,15,20,35].

Game Design for Learning

Despite recent attention on games and learning, there is limited evidence that games designed for learning are successful (see [18]). One common pitfall of game design is "focusing too heavily on educational content to the detriment of game play" [18]. In this respect, we found Salen and Zimmerman's definition of a game to be especially useful during our design process:

> *A game is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome.* [32, p.80].

Following this perspective, we felt strongly that we should create a *real* game (as opposed to an activity with superficial game-like elements). We worked hard to make sure that the game was not only fun and easy to play, but that it also *intrinsically integrated* the core mechanisms of game play with our target learning objectives (see [10]). In other words, to succeed in the game, players have to create scientifically valid phylogenetic trees. Moreover, the fun of playing the game derives directly from this activity.

BUILD-A-TREE DESIGN

To help visitors learn about evolution and tree thinking skills, we designed a multi-level puzzle game called Build-a-Tree (BAT). Our design was inspired by the work of Antle and colleagues on *Futura* [2] as well as by popular multi-touch puzzle games such as *Angry Birds* and *Cut the Rope*.

We used an eight-month iterative design process that emphasized user testing with increasing rounds of ecological validity. Our goal was to iron out usability issues while at the same time increasing engagement and learning. We started with informal testing with friends and colleagues followed by several rounds of testing in our lab with groups of children that we recruited for this project. Finally, we conducted observations of visitors using the exhibit in a museum prior to the start of our study. Through this process, our design evolved substantially.

We implemented our game using HTML5 and JavaScript with the goal of deploying on multiple platforms such as the Microsoft Surface, web browsers, and mobile devices like the Apple iPad. For this study, we used a first-generation Microsoft Surface that we placed on a raised platform to allow visitors to interact while standing. We used the JavaScript Web Socket interface to pump multi-touch events from a native C# application into a web browser (Google Chrome) running in kiosk mode.

Build-a-Tree asks visitors to construct trees showing the evolutionary relationships of organisms (Figures 1, 3). We represent organisms with black silhouettes superimposed on colored circles that visitors drag around the table. Touching any two circles together joins them into a tree. This same mechanism works to join organisms onto an existing tree or to join two sub-trees together. The reverse action, dragging circles apart, removes an organism from an existing tree. This mechanism also supports collaborative interaction as multiple players can work together, dragging and connecting organisms simultaneously.

We used a simple spring physics model to animate the construction and deconstruction of trees. This allows visitors to rearrange the left-to-right ordering of organisms without breaking their tree apart. As visitors construct correct sub-trees, we label shared derived traits (also called synapomorphies) that characterize that group of organisms. For example, in Figure 1, *Theropods* and *Mammals* are labeled with the synapomorphies, *wishbones* and *hair*. The order in which circles are connected determines the structure of the tree. In other words, organisms that are more closely related have to be connected before organisms that are more distantly related.

We designed the game levels to be increasingly difficult and to build on one another conceptually. For example, level four asks visitors to construct a tree showing the relationships of spiders, scorpions, and insects. These same relationships appear again as sub-problems in larger puzzles

Figure 3. A group of four girls (ages 8, 9, 11, and 13) playing Build-a-Tree at the museum. The solution tree is open at the top of the screen.

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on levels six and seven. The original version of the game included seven levels with an additional bonus level. The bonus level asked visitors to construct a tree with nine groups of organisms. However, after our first two days of observations, we reduced the number of levels to six because we felt that visitors were becoming too frustrated and spending too long at the exhibit (in excess of 20 minutes in some cases). To give a sense for the difficulty of the challenge, there are over two million possible ways to construct a tree with nine organisms.

During game play, visitors have the option of pulling down a solution (that we call the Scientist Tree) from the top of the screen (Figure 3). However, many visitors made a point to figure out the solutions without referring to the answer. To reinforce the idea that trees can be structurally equivalent without having identical left-to-right ordering, the game also asks visitors to do a side-by-side comparison of their tree with the scientist tree after completing each level. Afterwards, the game provides a short *did you know* explanation to highlight surprising or interesting facts about the relationships that were just presented.

Build-a-Tree provides real-time feedback on players' solutions. Visitors collect stars by joining trees correctly, while incorrect joins result in greyed-out tree branches. There is some flexibility in terms of how players complete levels—sub-trees can be assembled in different orders, and the left-to-right positions of organisms are not important provided that the branching structure of the tree is correct. However, compared to games like Futura [2], where there are many possible outcomes and correct solutions, Build-a-Tree is more restrictive. This represents a serious pedagogical problem for us. Many informal learning institutions have shifted away from thinking of the museum as the knowledge authority and instead now focus on empowering visitors to co-construct knowledge through exploratory, open-ended activities (e.g. [9,16]). We discuss ways to reconcile this design tension in the Future Work section below.

METHODS

Participants

This study took place over one week at the Harvard Museum of Natural History. In the first part of the study, we recruited 35 family groups in the exhibit hall containing the multi-touch tabletop. We obtained consent from parents and children to video record their interaction with the exhibit prior to participation. We define a family group as consisting of at least one parent and one child (6 to 16 years old). For this study we analyzed only 30 of the 35 groups. We excluded two groups because they did not speak English while using the exhibit and three groups due to technical problems with the video recording equipment. Of the 30 family groups that we analyzed, there were 84 individuals including 29 adults (19 women and 10 men) and 55 children (24 girls and 31 boys) from 6 to 16 years old with a mean age 9.1 years (SD = 2.8). The average group size was 2.1 participants.

To get a sense of visitor interaction under more naturalistic conditions, we observed an additional 50 social groups (104 individuals) who used the exhibit. We did not video record or interact with these visitors in any way. We recorded field notes, interaction times, and gender and age estimates. Based on these estimates, there were 59 adults (31 women and 28 men) and 45 children (27 girls and 18 boys) with a mean age of 9.3 years. The average group size was 1.98 participants.

Procedure

For our first group of participants, we invited families to use the exhibit as they would any other exhibit at the museum and to stay for as little or as long as they liked. We

Utterance Type	Description	Examples
Game Talk		
Turn Taking	Negotiation about shared participation in the game	*I want to play; My turn*
Narration & Coaching	Narrating game play or offering advice or feedback	*Pull that one out; We got a star!*
Pacing	Talk related to the pace of game play	*Wait, wait. Let's stop and think here.*
Reflection	Reflection on the game or quality of play	*Now it's getting much harder*
Content Talk		
Organism	Talk about organisms including features	*Mammals don't lay eggs.*
Grouping	Talk about how to group organisms to form a tree	*Birds and dinosaurs are related.*
Tree Structure	Comparisons to the scientist tree	*Well we're always mirroring the trees.*
Reflection	Reflecting on learning	*I didn't know that.*
Paraphrasing	Paraphrasing exhibit text	*Birds and lizards diverged more recently.*
Off-Topic Talk	Any talk not related to the exhibit	*Dad, I have to go to the bathroom.*

Table 1. Coding scheme for visitor utterances.

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set up a video recorder on a tripod to capture the tabletop surface and visitors' hands and arms. We also used a voice recorder on the surface of the table to capture a second audio stream to improve the quality of our transcriptions. The researchers observed from seven feet away while visitors interacted with the exhibit.

Coding

For the 30 families that we video recorded, we transcribed visitor conversation up to and including the first six levels of game play. Twenty-three families completed at least six levels; four families completed five levels; and the remaining families completed between one and three levels. These transcriptions included family conversations as well as notes on participants' physical interaction with the surface. We coded at the level of conversational utterances consisting of continuous units of speech without long pauses or interruptions. Two researchers delineated the transcriptions into conversational utterances. We achieved 86.5% agreement on utterance delineation based on an overlap of six random transcriptions (20% of the family groups). In total we coded 3,460 utterances: an average of 115 utterances per family (SD = 57.2) and 13.4 utterances per minute (SD = 6.14).

The same two researchers next coded utterances into one of five categories: *statements*, *questions*, *responses/answers*, *interjections*, or *reading text*. The purpose of this step was to compare our data with that of the Active Prolonged Engagement exhibits reported in [16]. We obtained 87% agreement based on 10% of the data (Kappa = 0.75).

Finally, we iteratively developed a coding scheme based on visitor conversation. This coding scheme includes three high-level categories: *game talk*, *content talk*, and *off-topic talk*. Game talk relates to social aspects of game play such as turn taking, game pacing, narration, and coaching. Content talk relates to organisms in the game, the groupings of organisms, and the phylogenetic trees that visitors construct. Lastly, off-topic talk refers to any utterance not directly related to the exhibit. The full set of codes is shown in Table 1. We obtained 79% agreement on these codes based on 10% of the data (Kappa = 0.68).

RESULTS

In this section, we start by comparing our results to that of Active Prolonged Engagement exhibits reported in [16]. We use holding time, off-topic talk, visitor questions, and collaborative engagement as comparison points. We then analyze visitor conversation at our exhibit in more detail, looking at content talk and game talk in particular.

Holding Time

The APE studies report that visitors spend around 3.3 minutes on average at APE exhibits. This is in contrast to 1.1 minutes at other traditional exhibits at the Exploratorium [16]. For comparison, we recorded holding times at our exhibit for all participant groups. Following [16], we define this as the time that the first visitor in a group starts using the exhibit to the time that the last visitor in that group leaves the exhibit.

On average, the families that we recruited spent 14 minutes interacting with the exhibit (SD = 6). However, this average is lower than it would have been because we had to interrupt some families after 15 minutes during busy times of day. Figure 4 shows a histogram of holding times for recruited visitors capped at 15 minutes. Because we recruited families to participate, we suspected that these results were artificially high. Among other factors, the visitors we recruited might have been more motivated to persist and succeed than they would have been otherwise. Therefore, to get a sense for visitor interaction under more naturalistic conditions, we observed an additional 50 social groups who used the exhibit. We did not video record or interact with these visitors in any way.

As expected, for the second group of visitors, the holding times were lower (Figure 5). The average holding time was 3.66 minutes (SD=4.68). This was on par with the 3.3-minute average holding time reported in [16] for APE exhibits. Of these groups, 28% spent more than 4 minutes

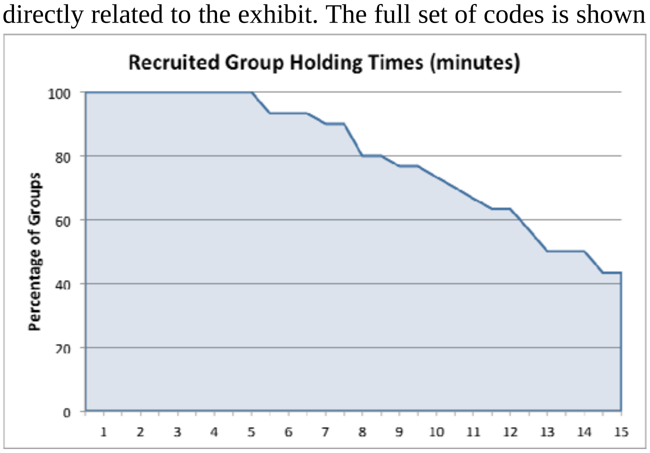

Figure 4. Holding times for the 30 families that we recruited to participate in our study.

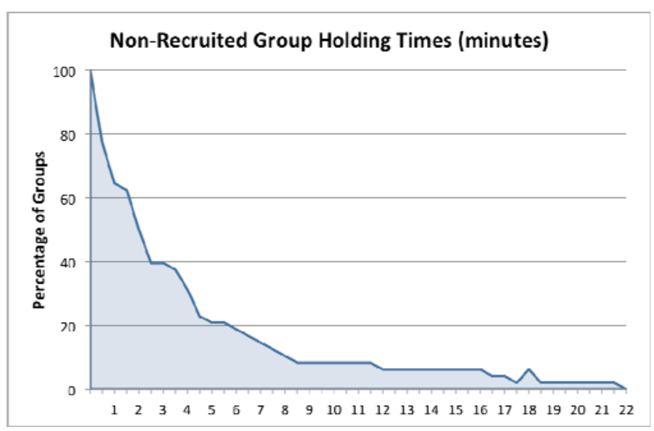

Figure 5. Holding times for the 50 groups that we did not recruit.

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interacting with the exhibit. Again, this is similar to the results reported for APE exhibits in which 28% of the groups also spent more then 4 minutes [16].

Off-Topic Talk

While the APE studies do not report on off-topic conversation, they do suggest that visitors are engaged and focused on exhibit interaction. For our study, participants that we video recorded engaged in little off-topic conversation while using the exhibit. Off-topic utterances constituted 1.2% of the overall conversation and occurred 0.16 times per minute on average (SD = 0.3). Off-topic talk included statements like, "look, mommy, it's a camera" or "I have to go to the bathroom." We only know the rate of off-topic conversation for the visitors that we video recorded. However based on the differences between groups in the holding time data, it is possible off topic talk was higher among visitors that we did not recruit.

Visitor Questions and Answers

Visitors at APE exhibits ask qualitatively different types of questions than they do at other types of exhibits [16]. APE questions tend to be *action* and *explanation* oriented and visitors are more likely to answer these questions by talking to one another or manipulating the exhibit rather than reading a label. Build-a-Tree visitors tended to ask fewer questions than visitors reported in the APE studies. APE participants asked 2-3 questions per minute, while Build-a-Tree participants asked 1.48 questions per minute (SD = 1.11). In our data, 62.25% of visitor questions involved *game talk*. For example: "How do you attach the tree?" or "You wanna try the last two and see what happens?" These types of questions seemed similar to action questions from the APE studies. Another 33.75% of visitor questions involved content talk. For example: "Animals and fungi? What's the similarity?" or "Remember how we talked about family trees today?" These questions seemed similar in nature to *explanation* questions described in the APE studies. Finally, 2.75% of visitor questions were off-topic.

Collaborative Engagement

One hallmark of APE exhibits is good support for visitor collaboration as a result of careful, iterative design [16]. One strategy that Exploratorium designers have used to support collaboration is to break single activity stations into multiple parallel stations. This helps avoid the problem of visitors interfering (intentionally or unintentionally) with one another as they manipulate the same exhibit elements. Even working side-by-side visitors can collaborate by sharing ideas or asking questions of one another.

In their work on Social Interactive Media, Snibbe and Raffle use the term *social scalability* to capture similar exhibit design principles [35]. First, as they put it, "the unbreakable rule is that if the exhibit fits more than one person, it must work with more than one person." And second, the experience should become richer as more people interact with the exhibit.

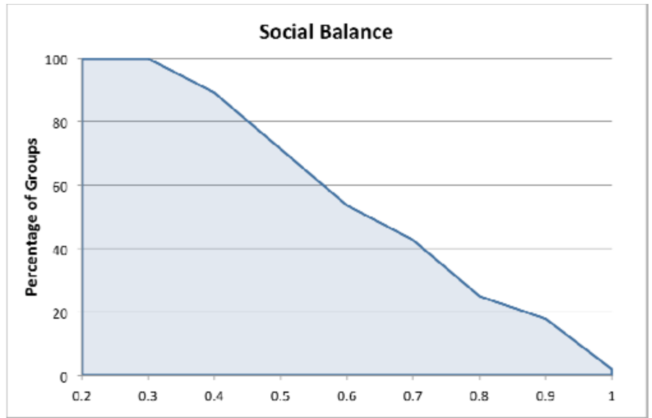

Figure 6. Social balance scores for the 28 visitor groups that we did not recruit and consisting of more than one person.

In this project we were concerned that the exhibits we were developing would not be socially scalable due, in part, to the relatively small display size of the Microsoft Surface (25" x 19"), which does not afford the same kind of parallel, independent works spaces as many of the APE exhibits. To assess this with the BAT exhibit, we developed a measure of *social balance*, to capture the degree to which visitors engaged in simultaneous active participation. For each group we took the sum of individual interaction times t_i divided by the product of the group interaction time T and the size of the group n.

$$balance = \frac{\sum t_i}{(T \times n)}$$

For example, consider a group of three visitors with a group interaction time of 3 minutes. If each member of the group interacts for only 1 minute each, the social balance score would be 0.33, indicating a low amount of simultaneous interaction. If, on the other hand, each of the individuals interacts for 2 minutes each, the social balance score would be 0.66, indicating a higher level of collaboration. This measure captures none of the nuance of social interaction (for example, visitors who interact verbally but not physically), but it does provide a general quantitative overview of group collaboration.

Starting with data from the 50 social groups that we observed unobtrusively, we examined the subset of 28 groups consisting of more than one visitor. Figure 6 shows a histogram of social balance scores for these groups. There is a relatively linear progression with 75% of the groups scoring 0.48 or higher, 50% of the groups scoring 0.6 or higher, and 25% of the groups scoring of 0.8 or higher.

Qualitatively, our sense was visitors were able to collaborate productively with our exhibit in part because they were able to apply existing social practices of game play in the museum context. We discuss this in more detail below.

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DISCUSSION

We feel that our results demonstrate that it is possible to achieve APE-like engagement with a tabletop exhibit in a natural history museum. However, Build-a-Tree offers visitors a different kind of learning experience than the APE exhibits described in [1,9,16]. In particular, APE exhibits tend to foster activities such as exploration, investigation, observation, and construction [16]. BAT, on the other hand, is a multi-level puzzle game and lacks the open-ended nature of APE exhibits. BAT also lacks the hands-on access to scientific phenomena that characterizes APE activities. Given this, one way to interpret the success of BAT, is that it offers visitors the opportunity to play a *real* game in the sense proposed by Salen and Zimmerman: a "system in which players engage in artificial conflict, defined by rules, that results in a quantifiable outcome" [32]. As such, visitors were able to to apply existing social practices of game play to manage and coordinate their interaction with the table and with one another.

Stevens, Satwicz, and McCarthy conducted an ethnographic study of children playing video games in homes [36]. Their account of video game play is less concerned with what makes video games successful learning environments (e.g. [6,18]) and more concerned with what makes kids successful learners. As such, they relate the diverse ways in which kids organize themselves to support learning while playing video games in homes. These *learning arrangements* include instances of coaching, active apprenticeships, peripheral observations and participation, and inner and outer circles of play [36].

Similar to observations of Stevens et al. [36], participants in our study exhibited a variety of successful learning arrangements around the tabletop. To help understand this, we explore the role of game talk in more detail.

Game Talk

Figure 7 shows that participants devoted a large portion of their total conversation to game talk (48.8%) with an average of 6.37 utterances related to game play per minute (SD = 3.17). While this may seem high, this type of conversation seemed to play a critical role in helping visitors maintain social engagement with the exhibit. Four sub-categories of game talk emerged from our analysis: *turn-taking*, *narration and coaching*, *reflection*, and *pacing* (Figure 8).

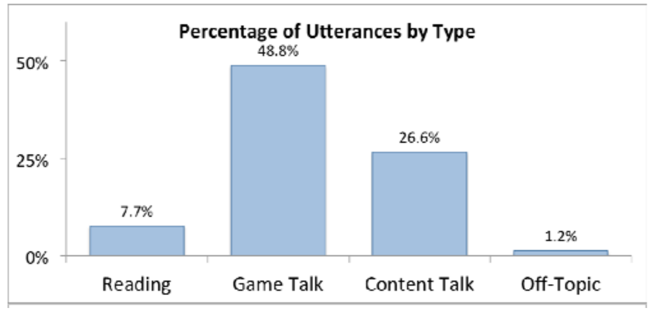

Figure 7. Percentage of visitor utterances by category type.

Turn Taking

Talk related to turn taking was common for groups with multiple children. It included negotiations for sharing the game play experience (e.g. "you can have a turn in a minute" or "let me try") as well as negotiation for physical orientation around the tabletop surface. This sort of talk seemed to help visitors to move between inner and outer circles of play while remaining engaged in the activity at some level of peripheral participation. It also gave them the opportunity to complain if they felt that the balance of participation was unfair. For example, this transcript involves two boys playing with our exhibit, each six years old:

B1: No, no. There. That goes there.
B1: No, there.
B2: Can I stand in the middle?
B1: Yeah, sure. In a minute.
B2: This time can I stand in the middle?
B1: Alright, sure.

In this example, B2 successfully negotiates for a central position in the game play in preparation for his turn on the next level. His brother accepts this new arrangement while maintaining a running commentary (or narration) of game play.

Narration and Coaching

Game talk related to narration and coaching included comments on game achievement and progress, play-by-play commentary, and coaching and advice for other players. Both narration and coaching appear to be common aspects of video game play in homes. Stevens et al. [36] provide several examples in which children coach each other on video game play, offering both solicited and unsolicited advice. In these cases, siblings and friends serve as *just-in-time resources* to scaffold learning around game play [36]. In our observations, we saw parents filling a similar role. The following transcript is from a family with two boys (age 8 and 6) and their mother. The older boy is playing the game while his mother and brother narrate play and offer advice:

Mom: Flying. Put flying ones.
Mom: They're not flying.

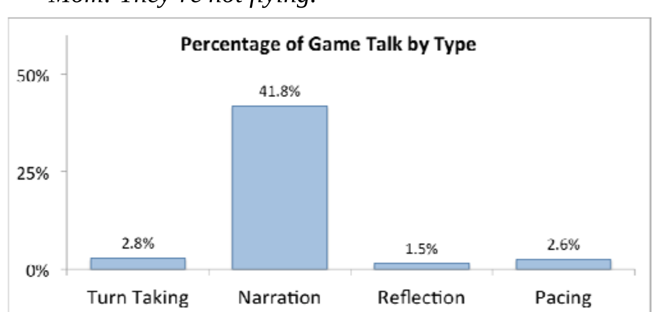

Figure 8. Percentage of game talk by families as a portion of overall utterances.

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Brother: Then stick them together.
Mom: When you have a star you've got it right... at the moment it's not…
Mom: So maybe split a little bit.
Brother: I'm gonna have a little peek at the answer. Don't look.
Brother: Don't look! (player tries to look at the answer)
Brother: (??) (looks at the solution again)
Mom: It's maybe something more than just flying not flying.
Player: Giraffe
Mom: Maybe something about how they give the baby…
Mom: Do they have an egg or not.

The younger brother, while not playing this level, is actively engaged in the game's progress and participates in ways that don't directly affect his older brother's play. The mother, meanwhile, provides active coaching on both the mechanisms of game play and on the evolution content. Interestingly, although only the older boy is actively playing the game, the other members of the group use coaching and narration as a way to stay involved in the game play.

Pacing

Talk related to game pacing seemed to serve three purposes. First it helped group members make sure they were all focused on the activity and ready to proceed (e.g. saying "OK, ready?") before starting the next level. Second, pacing was used as a way to control the progress of the game when multiple visitors were playing at the same time. For example, saying, "wait, stop." Often this involved proposing ideas for how to assemble the tree on more difficult levels, or proposing new player arrangements. For example, this transcript involves four girls playing together (ages 8, 9, 11, and 13):

Put the butterfly with giraffes.
Put it over right...
That's not right.
Wait. Stop, stop, stop.
It's not right.

The final role of pacing talk tended to come from parents and was used to try to impose points of reflection during game play. In other words, trying to get kids to stop and think. For example: "Wait, wait let's stop and think here." or "Wait. You have to read that [did you know text] out loud." This kind of participation is common for parents in museums (e.g. [37]). We suspect that it is also useful for keeping parents engaged in the activity because it provides an opportunity to integrate explanatory and interpretive content into the game play.

DESIGN IMPLICATIONS

Our research highlights potential advantages of tabletop games for learning in museums. Not only are games motivational, but they also cue a repertoire of social practices of game play that facilitate productive collaboration around the tabletop. There are, however, several pitfalls inherent in this approach that we discuss briefly in this section.

A first pitfall relates to the use of multi-level games in museums. In informal learning environments of museums, it is accepted practice not to constrain visitors to experience exhibit content in a fixed order. Tabletops (as well as other exhibits) can facilitate a variety of group interaction patterns [20] that can confound designs relying on one-group-at-a-time assumptions. The potential pitfall with multi-level games is that earlier levels are often used to scaffold game play in more advanced levels [6]. This was the case with our Build-a-Tree design. As a result we observed groups play the game for four or five levels and then wander away to make room for new visitors who, in turn, were confused by starting the game on an advanced level of play. To mitigate these problems, we recommend having only a few levels in a game (six seemed to be a good number for us). This also helped keep the amount of time that any one group spent with the exhibit at an acceptable level. Likewise, there should be easy and obvious ways for visitors to start the game over from the beginning. The trick is make sure that this mechanism is not too easy to trigger in order to avoid individual visitors accidentally (or even intentionally) restarting the game while other people are playing. Finally, as is common practice with many interactive exhibits, games should have a built-in timeout that automatically restarts the activity after around 30 seconds of non-use.

A second pitfall relates to our observation that many visitors (especially adults) are averse to the idea of playing video games in a natural history museum. While we were observing the Build-a-Tree exhibit, we overheard many parents and chaperones making comments along the lines of "we're not here to play games" in an effort to discourage children from playing. We suspect that this attitude is more common in natural history museums than in science museums because there are rare and authentic artifacts on display that can only be seen first-hand in galleries. Given this, we think that it is critical for tabletop games in museums to communicate their educational value to parents. Some ways to achieve this might be to make the content of the game directly related to the artifacts in the immediate vicinity of the tabletop. Or, as long as it is not required for game play, include explanatory labels like the *did-you-know* text in our game. This provides parents with a productive role to play in the activity: reading and interpreting the text for children [37].

Finally, designers should be cautious about relying on games at the expense of more open-ended inquiry activities in which visitors explore and answer their own questions by interacting with exhibit elements. At the heart of this design tradeoff is a question of pedagogical values. Why do we

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want visitors to interact? Is it for the fun of playing a video game, for personal interest, or for the curiosity and sense of wonder invoked when encountering something new and unexpected? Or can it be some combination of these? Even though this version of the Build-a-Tree design was successful in terms of its ability to engage visitors and support group interaction, we feel that we did not succeed in creating an activity that fully aligned with our own pedagogical values. Specifically, the game affords little opportunity for open-ended exploration, and the motivation to play the game seems to have less to do with personal interest in the topic of evolution and more to do with the challenge of solving the puzzles provided on each level. We are currently working on redesigns for this activity to address this.

CONCLUSION AND FUTURE WORK

In this paper we presented the design and evaluation of a tabletop game to help natural history museum visitors learn about evolution. To evaluate the success of our exhibit, we borrowed the concept of Active Prolonged Engagement from the science museum literature. Our results showed that visitors were engaged in focused, on-topic interaction with our exhibit for prolonged periods of time. We argue that this was due in large part to existing social practices of game play that visitors brought with them into the museum.

In the future we hope to explore ways to make Build-a-Tree more open-ended in the sense of APE exhibits. One way to accomplish this might be to include levels in which there is no known right answer or where there is still active debate among scientists. Another option is to allow visitors to manipulate both organisms and traits and to focus attention more on the tree structure itself. We also hope to conduct research on learning outcomes related to evolution and tree thinking.

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