Enhancing a Tangible Tabletop with Embedded-Technology Objects for Experiencing Deep Time

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Abstract. *Abstract concepts are harder to understand because they do not provide a direct sensory reference as concrete concepts do. Tangible interfaces have been shown benefits to facilitate the learning of such concepts through the manipulation of physical objects. In this work, we investigate the use of TangiTime, an educational exhibit designed and constructed as a tangible tabletop enhanced with embedded-technology objects to explore the concept of deep time. In particular, we were interested in the role of embedded-technology objects to support engagement and learning. We describe the TangiTime design process and artifacts implementation. Also, we present the context in which the exhibit was put into usage and results. Our results indicate that interaction with embedded-technology objects creates new ways of experiencing tangible tabletops and more engagement with the theme of the exhibit.*

1. Introduction

Literature has shown that tangible interfaces in computational environments designed for educational contexts allow a learning experience closer to how we live and interact with our physical environment. Tangible interaction can be combined with digital displays taking advantage of human abilities to grasp and manipulate physical objects and materials to create tangible tabletops [Ishii 2008]. In a tangible tabletop, physical objects can be manipulated on the tabletop display and their movement can be detected by it. The objects input are captured through detection of markers attached to their base, and the system output is displayed on the tabletop display. A large body of research work explores the educational potential of tabletops into computational learning environments mainly as highly supportive systems for collaboration and interaction [Dillenbourg and Evans 2011; Schneider et al. 2011]. Other educational benefits are the face-to-face interaction, facilitation of involvement and understanding of abstract concepts.

With the emergence of ubiquitous technologies, the low-cost and internet capabilities of devices, new modes of interacting with technology can be explored. However, there is a lack of research works that examine the potential of ubiquitous technologies to promote active and exploratory learning through tangible tabletops and embedded-technology objects. In this way, this work introduces TangiTime, a learning environment designed and constructed as a tangible tabletop museum exhibit enhanced with embedded-technology objects to explore the concept of 'deep time'. The concept of

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deep time refers to the time of geological processes, which are in the scale of millions or billions of years as the case of the geological history of our planet of 4.5 billion years [Dalrymple 2001]. Abstract concepts as deep time are harder to understand than concrete concepts because they lack the fairly direct sensory referents that concrete concepts have [Schwanenflugel 2013]. A way to approach the deep time concept is through the exploration of geological eras in which important biological and geological events occurred during the evolution of our planet. Metaphors are usually used to facilitate the understanding of abstract concepts; in this work we designed five embedded-technology objects to enable exploration within the exhibit installation. The tangible objects represent a natural component or a living organism that belonged to a certain geological era: a meteorite, a volcano, a dragonfly and two dinosaurs.

Several research works have demonstrated the benefits of tangible tabletop to learn abstract concepts. For example, Ma et al. (2015) present *Plankton Population*, a tangible tabletop museum exhibit to look at the distribution of phytoplankton in the oceans manipulating physical rings as magnifying glasses. The authors compared the behavior of museum visitors at an interactive exhibit that used physical versus virtual objects. They found that the physical rings better-afforded touch and manipulation compared to the virtual rings. Schneider and Blikstein (2016) present *Combinatorix*, a tangible tabletop that supports learning of probabilities. The authors examined the interaction between focused lectures and free exploration, and they found that students who first explored the topic on a tangible interface and then watched a video lecture significantly outperformed students who watched a lecture first. Loparev et al. (2017) present *BacPack*, a tangible tabletop museum exhibit for exploring bio-design. The authors compared two versions of the exhibit: one with tangible objects and one with virtual objects. They found that the tangible objects created opportunities for collaboration beyond those afforded by the multitouch only version. Morita et al. (2017) developed a tangible learning environment for learning Solar System that allows the users themselves to manipulate astronomical models of the sun, earth, and moon. Users can observe the phases of the moon and the positional relationships of the sun, earth, and moon in a virtual space.

A research project most related to our work is outlined by Raffaele et al. (2018). They developed a tangible educational environment for learning Artificial Intelligence by manipulating tangible objects with embedded technology that can change their color or be provided with movement. In addition to the research work found in literature, our educational exhibit allows users to interact with the tangible objects outside the tabletop display and continue to receive feedback on the object itself. Also, the tangible objects were provided with capabilities of communication between them, which allowed users to interact with a tangible object and generate feedback on another tangible object. We were interested in the role of the embedded-technology objects to support engagement and learning within the exhibit. Tangible objects with embedded technology enable an experience of learning in the physical environment, not exclusively in the digital display, transforming physical actions into physical effects.

In this paper, we describe the design process of the educational exhibit and the implementation of the artifacts. Next, we describe the methodology employed in a case study addressing the use of the installation, and the results and discussion of the study. Finally, we present conclusions and point to further work.

2. TangiTime – Design and Development

In this section, we detail the design process and the artifacts implementation of TangiTime installation. First, we describe the tabletop display design and development. Next, we describe the design and construction of the tangible objects.

2.1. Tabletop display

Tangible tabletops or interactive surfaces are a genre of Tangible User Interface (TUI) artifacts that transform surfaces into active interfaces making digital information directly actionable with our hands on the tabletop display [Ishii 2008]. We created three design alternatives to introduce the concept of deep time through the manipulation of physical objects to explore geological eras: Archean, Proterozoic, Paleozoic, Mesozoic and Cenozoic eras [Francisco 2019].

The first paper prototype consisted of a geologic timeline that extended over the complete interactive surface with representative images of geological eras along the timeline (Figure 1a). Users could interact with the timeline by manipulating the physical objects on specific areas defined by images. As a result, animations and information about the geological eras were displayed on the interactive surface. We considered that this prototype limited the interaction to very small parts of the interactive surface. Therefore, to increase the area of interaction, we designed a second paper prototype that divided the surface into five areas where each area represents a geological era (Figure 1b). Although this second prototype provided a larger area of interaction compared to the first prototype, this still limited the interaction to small parts of the interactive surface. Finally, we designed a third paper prototype where background images of each geological era would be randomly projected in the complete interactive surface (Figure 1c). In this way, Tangitime simulates the passage of time over geological eras through a random projection of background images on the tabletop display.

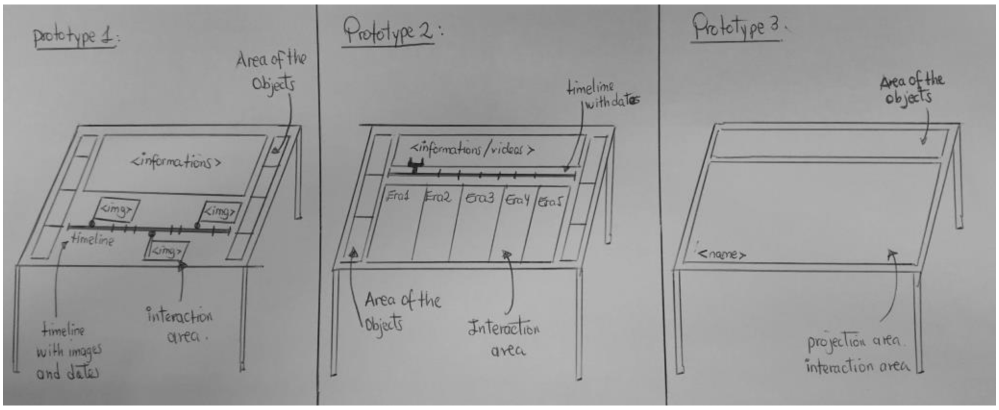

Figure 1. Design process: a) Prototype 1, b) Prototype 2, c) Prototype 3.

To implement the third prototype, we constructed a low-cost tangible tabletop capable of detecting special markers and five tangible objects with the markers attached to their base and embedded devices inside them. Our TangiTime system consists of a tracking system and a client application. As a tracking system, we used the reacTiVision framework [Kaltenbrunner and Bencina 2007], an open source, cross-platform computer vision framework for the fast and robust tracking of specially designed fiducial markers in a real-time video stream. Our client application was developed in Processing, an open-source graphical library and integrated development environment (IDE) to create applications with images, animation and sounds. The Processing program controls the interactive visualization projected on the tabletop display and the communication with an IoT platform that interconnect the tangible objects.

A random process displays background images of the first four geological eras (Archean, Proterozoic, Paleozoic, and Mesozoic eras) on the tabletop display. For the Cenozoic era, we decided to project a video that displays background images according to how the geological eras occurred during the evolution of our planet. Figure 2 shows a random background image and an object being manipulated on the tabletop display. The design and construction of tangible objects are described in the next section.

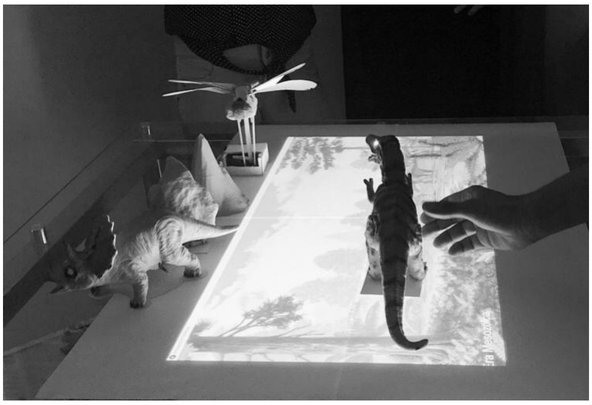

Figure 2. A random background image and an object being manipulated on the tabletop display.

2.2. Tangible objects

We selected images representing important evolutionary events as a natural component or a living organism of geological eras: a volcano, a meteorite, a dragonfly, a trilobite, three dinosaurs and Homo sapiens. Of the nine images, we selected five pictures to be designed and constructed as a tangible object: a volcano, a meteorite, a dragonfly and two dinosaurs (Figure 3). The volcano was selected to represent volcanic activity in the Archean era. The meteorite was chosen to represent meteorite falls in the Archean and Proterozoic eras. The dragonfly was selected to represent the presence of insects and for having wings. The idea in selecting this object was to provide physical effects on the object through the movement of its wings. The two chosen dinosaurs were a Tyrannosaurus Rex and a Tricerátops. They are probably the most popular dinosaurs for children and represent a dominant way of life in this era. The idea in selecting these objects was to explore the capabilities of communication between them.

We used 3D printing models to construct the volcano and the meteorite objects. In the dragonfly case, it was built manually using materials as wooden popsicle sticks, silicone and wires. Its wings were printed on paper and were provided with movement through a mechanism built using a servo motor. The dinosaurs are acquired toys with a soft structure that facilitated stuffing devices inside them and they have embedded RGB LEDs to light their eyes.

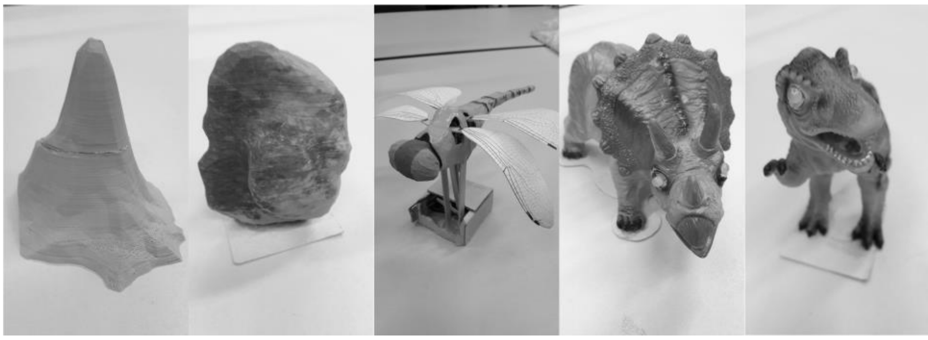

Figure 3. Tangible objects: A volcano, a meteorite, a dragonfly, a Tricerátops and a Tyrannosaurus rex.

As a result, the educational exhibit simulates the passage of time over the geological eras through a random projection of background images that represent environments of the geological era and allowing the manipulation of five tangible objects.

3. Methodology

We conducted a workshop to explore the benefits of enhanced tangible tabletops with embedded-technology to explore abstract concepts as deep time. We were interested in finding evidence to suggest that our technology learning environment allows children to understand deep time in an active and exploratory way.

3.1. Context and Participants

On January 12, 2019, we conducted a workshop titled "An Experience in Deep Time" that took place in the Exploratory Science Museum of the University of Campinas (UNICAMP). We exhibited three artifacts associated with the concepts of deep time and one of them was the installation described in this work. A prior registration was required to participate in the workshop because we enabled a limited number of places. In total, 15 children and adolescents between 7 and 14 years old participated in the workshop. The workshop lasted approximately two hours and a half and was composed of four different phases: 1) introduction, 2) exploration, 3) reflection, and 4) evaluation. We describe each of these different phases in the following subsections.

3.3.1 Introduction

During this phase, we introduced a presentation about the deep time concept, by raising motivational questions related to the subject and explained to the participants and their parents about the activities that would be carried out. As the workshop is part of a project approved by the university's research ethics committee (CAAE 72413817.3.0000.5404), we explained and handed to the participants and their parents the appropriate assent and consent terms that they signed.

3.3.2 Exploration

The participants were organized in three groups: GGreen, GRed, GHeart and identified by name and a group color tag. We explained to them that each group would start exploring one installation for some time and then they would receive an indication to explore the next installation. For each group that would have to explore our installation, we presented the tangible tabletop and the five objects to them. The participants were invited to manipulate the objects freely and discover if the object belonged or not to the projected geological era. Observing the characteristics of the projected image would help them to know which object should be manipulated and the feedbacks generated by the system would confirm their hypothesis (Figure 4). The participants had approximately 30 minutes to explore the installation before moving to another installation.

3.3.3 Reflection

In this phase, children wrote post-its comments and stuck on a blank flipchart sheet affixed on the wall. Each installation had a blank flipchart sheet affixed, to place feedback response to the following questions: How "deep time" appeared in the artifact? What do you like in the artifact? What do you do not like in the artifact? Additionally, children answered some challenge questions in a blank sheet regarding the concepts of deep time: "*Which geological era had the highest temperature of the planet*?", "*In which geological era did the first plants appeared*?", and "*In which geological era did a layer of primitive ozone appeared?*" (Figure 4).

Figure 4. Exploration (Left) and Reflection (Right) phases.

3.3.4 Evaluation

At the end of the workshop, we invited the participants to answer a printed version of an adapter AttrakDiff questionnaire [Brennand et al. 2018], anonymously, to assess the user experience at the workshop. Additionally, we used the Emoti-SAM instrument [Hayashi et al. 2016] to evaluate participants' affective response. The Emoti-SAM instrument consists of 15 emoticons, representing the three dimensions: pleasure, arousal, and dominance. Each dimension has a scale of 5 emoticons, going from the most positive to the most negative or the opposite (Figure 5). The participants had to pick the emoticon that best represented his emotional state towards the workshop and then to deposit it in an urn.

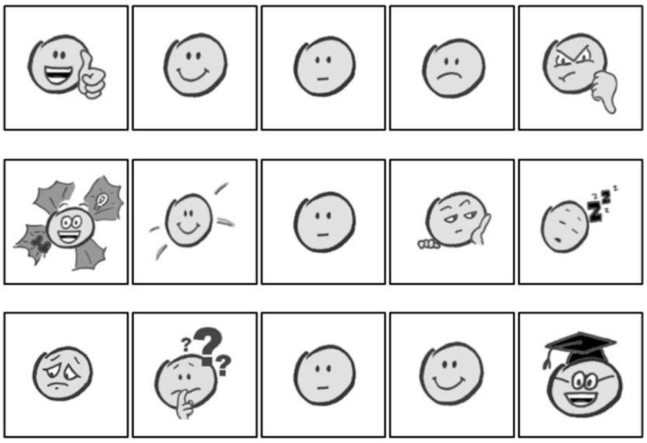

Figure 5.The Emoti-SAM instrument.

4. Results and Discussion

In this study, we explored the use of TangiTime, a technological learning environment designed and constructed as a tangible tabletop museum exhibit to explore the concept of 'deep time'. In particular, we were interested in the role of the embedded-technology objects to support engagement and learning within the exhibit.

We conducted a workshop and at the end of it, we provided children with three challenging questions on a paper sheet related to the subject, and questions about what they liked or did not like about the installation to answer in post-its and stuck these on a blank flipchart sheet. Post-its results show that all children mentioned only aspects that they liked, such as "It was the coolest!", "I really liked it", "Nice to know about the geological eras", "I enjoyed playing!". These comments suggest an enthusiasm of the children towards the installation. Understanding more about the learning of deep time, results show comments as: "I learned that events were divided into geological eras", "I learned that every animal has its era", "I learned that every animal has a place to live", "I learned about the ages, their names and objects".

In the results of the challenging question "*Which geological era had the highest temperature of the planet*?", we found evidence of the relationship of the tangible object, the animations and the characteristics of the projected image. Some answers were: "The era in which meteorites fell and volcanoes exploded", "Archean, because it had meteorites", and "Archean, because the world was covered with lava". In the results of the challenging question "*In which geological era did the first plants appeared*?", some answers were: "The Era of Insects", "The Era of the dragonfly", "The Era where the dragonfly appeared", and "The Era where the dragonfly emerged". These results suggest that the dragonfly seemed to have an important role as children more readily used terminology like "dragonfly" to answer the question.

We note that there was greater acceptance of the embedded-technology objects, which was reflected in the conflict cases children show, competing to manipulate the dragonfly or the dinosaurs (Figure 6). One child said, "Now I have the stone", referring to the meteorite and exposing his discontent because this object did not generate any feedback in the object itself. We found evidence of this presumption of acceptance of objects in the post-it comments too; for example, a child wrote: "I liked that when I placed the object on the table something was lighted”. The comments also suggest that the most popular objects were the dinosaurs, as they were the objects mentioned in comments such as: "I liked many things and the dinosaurs!", "I learned about dinosaurs" or "I learned that dinosaurs live in their own environment". We found that embedded-technology objects as the dragonfly and the dinosaurs create more engagement when compared to objects without embedded technology as the meteorite.

Figure 6. Two children competing to manipulate the dragonfly.

Figure 7 shows the results of the workshop evaluation with Emoti-SAM. In total, we collected 15 emoticons (one per participant) and they were grouped and counted manually. Of the 15 children who participated in the workshop, 6 children chose the most positive emoticon of the pleasure dimension represented by the happy face with the thumb up; 4 children chose the second most positive emoticon of same dimension represented by the smiling face; 3 children chose the most positive emoticon of the dominance dimension with the emoticon representing intelligence with graduation hat; and 1 child chose the second most positive emoticon of the arousal dimension. Only one child chose a negative emoticon. These results suggest that participants' affective response were positive.

Emoticon	Quantity
	1
	1
	3
	4
	6

Figure 7. Results of the evaluation with Emoti-SAM.

5. Conclusion

The emergence of ubiquitous technologies, the low-cost and internet capabilities of devices enabled opportunities to enhance tangible tabletops with embedded-technology objects. In this work, we present TangiTime: a tangible tabletop museum exhibit installation enhanced with embedded-technology objects to explore the concept of 'deep time'. Embedded-technology objects enable new ways of interaction, transforming physical actions into physical effects in the environment, not exclusively in the digital display. The results of this study suggested that embedded-technology objects generate more engagement than other tangible objects.

Due to the complexity of understanding abstract concepts such as deep time, we do not envision our educational exhibit as a stand-alone teaching tool. Instead, we consider it as a technology learning environment for students to trigger their interest towards understanding deep time in an active and exploratory way. As this work referred to an exhibit conducted in a science exploratory museum, further work could be done considering it as part of a formal learning process with school students and their teachers, for example. Also, from the technological point of view, more work will continue to be done to explore the role of embedded-technology objects and tangible tabletops in educational scenarios to provide them with a socioenactive experience with abstract concepts.

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